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THE UNIVERSITY OF ALBERTA

COASTAL EROSION IN PART OF THE BAY OF FUNDY, NOVA SCOTIA

by

© KENNETH W. THOMSON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1979

Cliffs east of Hall's Harbour at The Cove.

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Coastal Erosion in Part of the Bay of Fundy, Nova Scotia, submitted by Kenneth W. Thomson in partial fulfilment of the requirements for the degree of Master of Science.

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.....

.....

Date May 11, 1979

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Dr. A. J. Bowen of Dalhousie University purchased

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ABSTRACT

The funnel shaped Bay of Fundy lies between Nova Scotia and New Brunswick and is best known for its great tidal range (up to 18 meters in some locations). The south coast of the bay from Baxter's Harbour to Parker's Cove, a distance of approximately 85 kilometers, is largely a cliffed, rock coast composed of basaltic tholeiites. Coastal erosion, primarily in the form of cliff retreat, has given rise to a variety of forms including shore platforms, debris accumulations, caves and storm ledges.

This study examines the problem of coastal erosion in an attempt to assess the significance of tidal range as a contributing factor. The rate and scale of coastal erosion may be directly related to increasing tidal range as a result of (1) increase in area of cliff face exposure to marine processes and (2) a concomitant increase in range of groundwater fluctuations. The study is ordered in terms of the interaction of environmental controls (e.g., lithology, climate) with process factors (e.g., weathering, joint dilatency), to produce contemporary products (e.g., cliffs, shore platforms and beaches) and long term resultants (shore morphology).

Several erosional forms have been identified and described. These include the products of slab failure, rockfalls, granular disintegration, and bank slumps. Products of micro-scale erosional processes, such as mechanical and chemical weathering, are also discussed. It is demonstrated that the rate and scale of coastal erosion, in terms of

frequency and magnitude of debris accumulations, gradient of shore platforms and cove indentation, increase upbay as does tidal range. Furthermore, the significance of wave refraction decreases in the same direction. As there is some evidence to support the concept of increased range of groundwater head, concomitant with tidal range increase, it is concluded that tidal range strongly influences coastal erosion, principally through triggering sub-aerial processes of cliff retreat and shore platform evolution.

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CHAPTER I

INTRODUCTION

Geologically rapid changes of coastal morphologies are relatively common, particularly if coasts are backed by unconsolidated sediments such as those of dunes, deltas, till and outwash masses. Often overlooked, however, is the fact that rocky coasts or cliffed coasts composed of highly consolidated materials also quite often undergo rapid, severe, morphological alterations. An excellent example of this case is the south coast of the Bay of Fundy, Nova Scotia.

The Bay of Fundy is an area which has been the subject of little coastal geomorphological research. It is funnel shaped, dividing into two segments at its eastern end. These segments are the Minas Basin to the south and Chignecto Bay to the north. The Bay of Fundy and Chignecto Bay serve to separate mainland Canada from the peninsula of Nova Scotia. The bay is most widely known for having one of the greatest tidal ranges anywhere in the world - ranges of greater than 17 meters having been recorded.

The bay is of importance as a center of fishery and as a shipping terminus for Saint John, New Brunswick. However, modern fishing techniques have resulted in severe depletion of the fish stocks. Port use along the bay is severely restricted due to the extreme tidal range. Thus to date this has been an area of only minor economic importance.

This study is confined to the southern margin of the Bay of Fundy, along a 87.5 kilometers segment of coastline,

as indicated on Figure 1.1 and described in section 1.41.

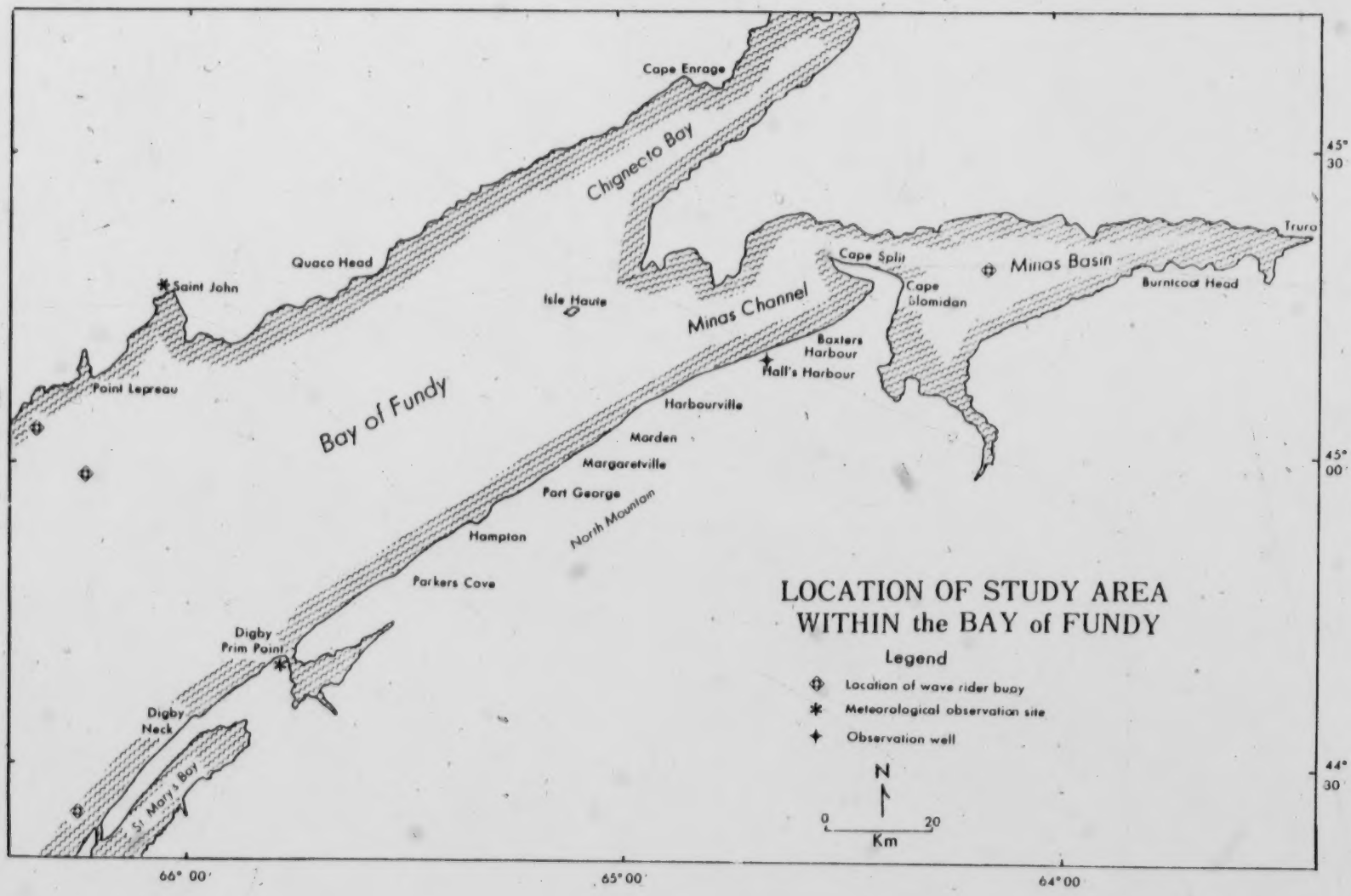
1.1 Problem and Objectives

The major manifestation of coastal, morphological change in the study area is erosion, principally erosion of the backshore cliffs through processes accentuating instability in the rock masses. These processes take the form of rockfalls and/or slab failures (Carson and Kirkby, 1972). One of the earliest descriptions of rock instability in this area was made by Abraham Gesener, writing in 1836. He described an event which took place near Hall's Harbour in the area now referred to as The Cove, but then called Cranberry Cove;

> About a mile eastward of the landing-place there is a notch in the trap rocks called Cranberry Cove. It is only remarkable for the height of the precipice, and the beautiful torrent rushing over its crest into the sea. In noticing this place we are reminded of one of those catastrophes common upon the coast. Seated upon a rock, enjoying the remainder of a scanty lunch, and occasionally sipping the best and purest beverage from the brook at our feet, suddenly the rocks trembled, and a noise loud as thunder, directed the eye to the westward, where a cloud of dust and smoke ascended upwards from the beach, then half covered by the flowing tide. An avalanche had taken place, and an immense mass of trap which had stood an hundred and fifty feet high, had fallen headlong upon the beach and into the Bay. The surface of fallen rocks had occupied nearly an acre, which was covered with large trees of birch and maple: some of these were buried in the debris, the remainder formed an immense raft that floated out to sea. Had we been seated a short distance farther westward, the event would never have been recorded by a living witness. The ruins thus produced form a great impediment in travelling along the shore, and several years will elapse before the sea will have removed the amorphous blocks now leaning against the cliffs.

Gesener's description serves as an effective illustration

Figure 1.1


Cape Enrage
Chignecto Bay
Quaco Head
Saint John
Isle Haute
Minas Channel
Cape Split
Minas Basin
Truro
Cape Blomidon
Burntcoat Head
Baxters Harbour
Hall's Harbour
Point Lepreau
Bay of Fundy
Harbourville
Morden
Margaretville
Port George
North Mountain
Hampton
Parkers Cove
Digby Prim Point
Digby Neck
St Mary's Bay
45° 30
45° 00
44° 30
66° 00
65° 00
64° 00
LOCATION OF STUDY AREA WITHIN the BAY of FUNDY
Legend
Location of wave rider buoy
Meteorological observation site
Observation well
N
0
20
Km

of a cliff retreat event characteristic of the Bay of Fundy. It also accentuates the fact that the process is ongoing and has not been initiated in recent times.

Of the 85 kilometer long study zone, approximately 60 kilometers have significant cliff development and are subject to erosion. Both to the east and the west of the study area additional cliffs exist, also undergoing erosion. Basalt exposures are predominant along the Nova Scotia Bay of Fundy Coast from Digby-Neck, Long Island to Scot's Bay. Within these limits the mean tidal range is known to increase from 5 meters in the west to approximately 10 meters at Scot's Bay. Within the study area itself the mean tidal range increases 2.3 meters from Parker's Cove to Baxter's Harbour (Canadian Hydrographic Service, 1978).

It is suggested here that a difference in tidal range between any two points (e.g. opposite ends of the study area) leads to a difference in range of cliff face exposure to wave attack and, perhaps more importantly, a difference in amplitude of groundwater table fluctuations in response to tidal fluctuations. These may be two important threshold factors in determining the probability of cliff failure. This study examines that probability by attempting to test the following hypothesis:

As tidal range increases eastwards up the Bay of Fundy the rate and scale of mass movement processes increase in response to (a) the tidal influence on groundwater pressure variations and b) the greater cliff base range over which wave attack is concentrated.

With respect to the hypothesis, this study examines the controlling variables, processes and contemporary products of coastal cliff evolution found within the bay. The expressions of process magnitudes and frequencies are compared on a longshore basis with a view to either proving or disproving the above working hypothesis.

1.2 Justification of Study

A study of coastal dynamics within this region may be justified in terms of two perspectives. From a socioeconomic standpoint the results of such a study quite possibly may be of significant value. The fact that such a potential application exists introduces the second perspective which may justify this study. That is, from a pure geomorphic standpoint, no comparable work has been done, to date, within the area on mass movement and general coastal dynamics. A review of the present literature as presented below (Section 1.3) demonstrates this fact. With increasing summer utilization of the area, coastal erosion is becoming a significant natural hazard. This has been recognized as an accelerating trend along the Atlantic seaboard of the United States (Mitchell, 1974), and is certainly of significance in this study area. Settlements such as Long Beach, Huntington Point, Harbourville, Turner Brook, Meeken Brook, Morden and Margaretville are all undergoing increasing exposure to coastal erosion as a natural hazard, leading to accelerating economic losses.

Early records and accounts (e.g. Gesener, 1836) describe the processes and effects of coastal erosion in the

area. These reinforce the intuitive assumption that such phenomena are dynamic responses linked to natural coastal processes. However, in recent years it has become quite obvious, on an international scale, that some coastal changes are direct responses to human use of the coastal zone (Mitchell, 1974; White and Hass, 1975; Komar, 1977). Human alterations of the coastal zone within the study area most often take the form of wharf construction. The effects are most noticeable in areas with prominent till exposures, such as at Hampton or Port Lorne. However, changes in the form of upbeach accretion and downbeach erosion have been noted in all areas where wharves are presently in use or were at one time. Recognizing that from a benefit-cost viewpoint such installations are often necessary, an understanding of the dynamic coastal processes involved, should provide a basis for more compatible design and implementation of structures in the coastal zone.

1.3 Literature

A literature search related to coastal erosion, coastal cliff erosion on resistant cliffs and coastal erosion in Canada, especially the Bay of Fundy, revealed an increasingly sparse array as the themes became more selective. Many areas directly and indirectly related to the above topics have been discussed at least superficially in the literature. However, very few studies have focused on the specific topic examined in this study. The following discussion reviews this problem. It organizes the relevant literature into the categories of a) general coastal studies b) slope process

studies c) studies of related coastal phenomena and d) Bay of Fundy studies.

a) General coastal studies:

Most general texts on coastal studies devote little attention to cliff morphology and its evolution. King (1972), emphasized this fact, and Bird (1972) was slightly more specific, outlining a close relationship between coastal morphology, cliff lithology and structure. The main focus of his discussion, however, was on the formation of shore platforms and their relationship with coastal process equilibria.

Zenkovich's (1967) work is very useful because it presents the western reader with a new school of thought in certain areas. He lists several factors, in addition to waves, that may have a destructive influence on coasts. These include mechanical (such as floating ice or driftwood), physical (thermal effects of seawater on frozen shores), physico-chemical (weathering in the wetted zone) and biological factors. Zenkovich (1967) is one of the few coastal geomorphologists to investigate the role of sea ice (both pack and drift forms) in coastal erosion, citing cases of ice protection and of ice abrasion.

Davies (1973) examined cliff types on a world scale and noted that two basic groups of processes are involved in cliff development; 1) undercutting and/or oversteepening by marine action and, 2) subaerial mass movement combined with removal of waste by waves.

b) Slope process studies:

Little literature exists on slope processes in coastal areas. Most work that is applicable to this study has been done either in alpine areas or along the walls of Norwegian fjords.

Carson and Kirkby (1972) classified instability processes of rock masses into four classes; 1) slab failure, 2) rock avalanches, 3) rockfalls and 4) granular disintegration. This terminology will be used in the present study.

Bjerrum and Jorstad (1957, 1968) found that rockfalls in Norway displayed a seasonal frequency of occurrence. Terzaghi (1962a), working on rock avalanches, found that cleft water pressure plays a significant role in rock mass instability. Wyrwoll (1977) examined rock-slope failures in the Labrador-Ungava area and suggested that frost wedging was not as important a factor in slope failure as previously supposed.

c) Studies of specific related coastal phenomena:

McLean and Davidson (1968) suggested that storm waves are not the prime agents of shore platform production along the Gisborne coast of New Zealand but that mass movement and removal of resulting waste by wave action is the main expression of erosion. Sunamara (1973) examined the role of waves in cliff erosion. He suggested a quantitative method of assessing critical wave height that would cause erosion on a specific rock type.

Kirk (1977), in his shore platform work on the Kaikoura

Peninsula, New Zealand, discussed the relationship of shore platform development to sea level changes. Trenhaile (1971, 1974a, 1974b, 1978) and Trenhaile and Layzell (1979) have shown that platforms are higher on exposed headlands as compared to those in bays. They have also reported significant correlations between platform gradients and tidal ranges and hence between cliff base elevations and high water levels.

d) Bay of Fundy Studies

Gesener (1836) was responsible for designating the North Mountain area (of which this study area is part) as one geologic unit which he called the "Trap district". With respect to coastal erosion he intuitively attributed the main cause of cliff failure in the area to frost wedging, with secondary effects of wave undercutting.

The study area lies within the Acadian Triassic Zone, of which Powers (1916) made the most significant advancement in study. He divided the Acadian province as three geologic units, one of which was the "North Mountain group". The North Mountain basalts encompass the whole of this study area. Unfortunately, the most detailed of Power's (1916) work was concentrated at three specific sites, all of which lie outside of the present study area.

During 1920-25 a few studies dealt in part with specific aspects of the coastline of the Bay of Fundy. Churchill (1923) was among the first to recognize that the coastal basalts are undergoing continued retreat. He suggested a rate of 15 centimeters to 30 centimeters (6 inches to 1 foot) of retreat annually. Although no empirical evidence was

presented in support of this, it is still a figure that is often quoted today (e.g. Owens, 1976). Goldthwait (1924) described the mechanics of erosion as he interpreted them, along the Bay of Fundy coast. These mechanisms included the quarrying power of waves, especially in susceptible lithologies.

It was not until 1958 that any comprehensive examination of the North Mountain region was made. Hickox (1958) produced detailed work on the Pleistocene geology of the area, principally obtaining evidence of a local re-advance following the last glaciation. In this respect he examined numerous till exposures along the coast.

Hudgins (1960) totally encompassed the present study area with his intensive geologic investigation. He devoted a large amount of time to mapping flow structures and identifying structural features such as columnar jointing, sheet jointing, synclinal and anticlinal axes, faults and joints. His mapping of primary and secondary joint patterns is of special interest for the present study, as are his references to coastal erosion in relation to identifiable features.

The Bay of Fundy is an area which has been subjected to changing sea levels since the last glaciation. Grant (1970), in dealing with the subject of coastal submergence in the Maritime Provinces, postulated a sea level rise of 30 centimeters per year for the Bay of Fundy area, the major portion of which is an anomalous rise as compared to eustatic rates determined for the Atlantic seaboard.

A number of studies have been primarily concerned with

sedimentation in the Bay of Fundy. For example, Swift et. al., (1973) produced a fairly comprehensive synthesis of data with respect to the local marine geology, coastal geomorphology, tides and sea ice. This study was expanded on by Pelletier (1974).

Rather meagre work has been done on ice conditions in the Bay of Fundy. Hind (1875), confining his work largely to Minas Basin and Chignecto Bay, made several observations on the efficiency of sea ice as a mode of sediment transport. One hundred years later, Knight and Dalrymple (1976) examined the sedimentological significance of winter conditions as they relate to morphologic preservation in the Bay of Fundy.

The most recent work related to the present study is that of Owens (1977). He classified coastal regions in the bay and presented his discussion in terms of this classification. Relevant data on climate and of the area tides were also included.

1.4 The Physical Setting

1.4.1 Location

The study area under consideration is a 87.5 kilometers segment of coastline along the southern margin of the Bay of Fundy. It is bounded on the southwest by Parker's Cove (44° 49'N, 65° 31'W) and on the northeast by Baxter's Harbour (45° 14'N, 64° 31'W). This area is located in the central part of the Bay of Fundy, with the major port of Saint John, New Brunswick, lying slightly to the northwest.

1.4.2 Geology

Swift et.al., (1973) describe the Bay of Fundy basin as lying in a Triassic half-graben, comprising basalts and red-continental mudstones. Hudgins (1960) states that North Mountain basalts are tholeiitic basalts originating from a series of flows that trend from Cape Split in a southwest direction and have an inferred thickness of over 200 meters.

A large number of flows can be identified in various cliff exposures, but there are only three flows that are consistent throughout the study area. These are the two top flows (9 meters and 11 meters thickness respectively) and the bottom flow with an inferred thickness of 95 meters according to Hudgins (1960). These three flows are thought to have come from a major magma reservoir to the northeast of the Blomidan - Cape Split area. Numerous intermediate flows occur also between the two top flows and the basal one. These intermediate flows are considered to be of local origin, on the basis of their limited extent and the presence of some small volcanic necks in the area.

Hudgins (1960) suggests that pre-existent Paleozoic fault planes may have been responsible for the initial lava extrusions. Maximum movement of these planes following the last extrusion may have been responsible for most of the deformation of the Acadian Triassic rocks. This is consistent with the theory that the Bay of Fundy is a result of longtitudinal faulting.

The general structure of the flows is monoclinal from Scot's Bay to the southwest. An exception to this is a

series of gentle folds in the form of anticlines and synclines. Hampton and St. Croix Coves are located on anticlinal structures. Port Lorne, Port George, Margaretville, Morden, Harbourville and Hall's Harbour are all situated along synclinal trough lines.

Only one fault was observed in the area, situated 1.5 kilometers west of Black Rock. This was also noted by Hudgins (1960). It has a downthrow of approximately one metre on the northeastern block. In contrast to infrequent faulting, an exceptionally high degree of jointing occurs within rocks of the study area. On the basis of their orientation and expression these joints can be divided into two groups primary and secondary. Primary joints have two preferred general orientations, 30° and 300° (from true north). They are near-vertical and frequently cut through the complete flow series. The secondary joints are oriented at approximately 20° and 275° and are usually curved, cutting obliquely through one or more of the flow members. Hudgins (1960) suggests that the primary joints were formed prior to the above folding, possibly as a result of longitudinal block faulting to the immediate north. The secondary joints may then have formed at the same time, or immediately following, and were a product of the warping which led to synclinal and anticlinal development.

In addition to the structures mentioned above, several other features of the North Mountain basalts are significant with respect to this study. Columnar joints are dominant in both the top and bottom basalt members. Flow units, which

are an expression of multiple flows in places and appear as small tongues of lava that have broken through other older flows, are fairly common. This often leads to a great many flow contacts at a single cross-section of the cliff face. Also significant in local areas is the presence of interflow sediments. They are usually fluvial or lacustrine deposits and thus correspond to relict, between-flow, stream beds or ponding zones.

1.4.3 General Geomorphology

Goldthwait (1924) (following W.M. Davis' 1895 theory of "the cycle of erosion") suggested that the southern half of the Maritime Provinces was once a complex geologic surface which became eroded to a peneplane. Portions of present day Nova Scotia exist as remnants of this peneplane, the largest remnant being the North Mountain. The North Mountain might be described as a cuesta. Its south face is an erosion scarp while the north slope follows the dip slope of the basalts to the coast.

Drainage from the North Mountain is regularly spaced and, to a large extent, structurally controlled. The primary structural control appears to be the north-northwest predominant joint pattern. The majority of drainage takes the form of small streams, all of which have downcut through till deposits to bedrock. Some are graded to the level of the backshore, while others have been left hanging, indicating a more rapid rate of cliff erosion than stream downcutting.

Pleistocene deposits and features are of geomorphic importance in restricted areas along the study coast. Most striking is the delta at McNeily Brook, about 1.5 kilometers west of Margaretville. The delta is locally known as the "Sand Banks". Named the McNeily Delta by Hickox (1958), it is considered to be a by-product of outwash from the last glaciation of the area. This was a northerly advance from a local ice center, following the last main Laurentide Glaciation. Except for initiating this delta, the local ice advance had little effect on the morphology of the area. A small U-shaped stream valley, 0.5 kilometers east of Margaretville (Figure 1.2), is one of the few exceptions to this. Little till was deposited, once the ice crossed the crest of North Mountain.

Figure 1.2 - U-shaped stream at Margaretville

The general configuration of the coastline from Parker's Cove to Hampton is straight. It has a very low backshore and is generally fronted by rock ledges and shore platforms 50 to 100 meters wide. From Hampton to Baxter's Harbour, the coast becomes highly indented. Numerous elliptical indentations, locally referred to as coves, exist in addition to points and ledges. Most of this shore segment is backed by cliffs ranging in height from 6 to 33 meters with a mean height of 18 meters. Shore platforms are generally well developed, some displaying a low tide cliff or erosion scarp. Cliff debris abounds in this area, often extending to the low tide level, forming temporary points which afford localised protection of the cliffs.

A proper analysis of this area must be based on a coastal classification scheme. Recognizing that, in Davies' (1970) terms, the Bay of Fundy shore line is a high energy, storm wave, macro-tidal environment, classification in this case is taken somewhat further and features are examined at a vastly changed scale. A highly modified version of Owen's (1974) classification scheme is thus used here. In this particular area the shoreline consists of two basic types; highly resistant shorelines and poorly resistant shorelines. Each of these is divided into several sub-categories. These categories, and examples of each, are contained in Table I. Figure 5.5 presents a complete classification of the study area coastline.

TABLE 1-1

COASTAL CLASSIFICATION SCHEME

I Highly-Resistant Shorelines

a) Cliffed

1) Shore platform devoid of sediment, e.g. Kirk Brook

2) Shore platform with abrading tools, e.g. Black Rock

3) Shore platform with beach at high tide; e.g. Morden east

4) Shore platform with coarse protective sediment cover and/or boulders, e.g. Hall's Harbour - The Cove

b) Non cliffed

Low backshore ledge allowing storm surge access, e.g. Parker's Cove

II Poorly-Resistant Shorelines

1) Steep beach face slope, e.g. McNeily Brook

2) Level beach, eroding backshore, e.g. Hampton

1.4.4 Physical Oceanography

(a) Bathymetry:

The main basin of the Bay of Fundy displays isobaths that roughly parallel the shoreline configuration. Unfortunately, the nearshore bathymetry has not been accurately surveyed for the bay. Available hydrographic maps are based on Admiralty Surveys of 1852. In general, however, the bay displays a relatively gently sloping long profile dipping in a westerly direction from the Minas Channel where the maximum depth is no greater than 100 meters. The gradient soon steepens and from Isle Haute to Grand Manan Island a sharp drop occurs. The gradient across the bay mouth shows a much steeper profile on the south shore than on the opposite shore. However, in the central part of the bay, from Margaretville to east of Saint John, slopes off both shores are approximately equal.

(b) Tides:

The tidal range is amplified up bay in an easterly direction. The mean tidal range within the study area increases from 7.1 meters at Parker's Cove to 9.9 meters at Baxter's Harbour. This tidal amplification is considered by some to result from the length of the Bay. The length apparently approximates the critical length required for resonance with a period of 6.28 hours (approximately one half the period of the diurnal tidal wave) (Pelletier, 1974; Grant, 1970). A second possible explanation states that the shape of the Bay of Fundy, combined with the adjacent Gulf of Maine, leads to shoaling on the continental

shelf and results in amplification of the tidal range with increased shoaling up bay (Harleman, 1966).

The tides in the Bay of Fundy are semi-diurnal. There are pronounced differences (as much as 3 meters) between meap and spring tide levels. A series of counter-clockwise, residual, tidal currents arise as a result of a net difference in the flow volumes of the flood and ebb tides. These currents are near-shore currents and their velocities in the intertidal zone have been observed to range from 0 to 1.5 meters per second (Knight and Dalrymple, 1976). These figures may be very significant insofar as observed velocities of the main tidal current in the central part of the Bay range from 0.75 meters per second to 2 meters per second. Both the residual currents and the main tidal currents increase in velocity within Minas Channel, especially toward Cape Split (Cameron, 1965).

c) Waves:

The Bay of Fundy is somewhat sheltered from storm-waves as compared to the Atlantic coast. However, the main basin of the bay is aligned with the principal wind directions (see climate section below) which allows considerable fetch and amplification of waves in an easterly direction. This is most significant for easterly facing areas and is less significant for the study area which is predominately north facing.

Swift et.al., (1973) calculated that during the winter, waves greater than 0.3 meters high occur 90% of the time, waves greater than 1 meter in height occur 50% of the time

and waves greater than 4 meters high occur 10% of the time. They stated that these wave heights are 5-10% less frequent in summer.

1.4.5 Climate

The climate of the Bay of Fundy is temperate with a strong continental influence due to the predominately easterly track of storms. There is a lack of weather monitoring stations in the area and most data are abstracted from data compiled at Saint John, New Brunswick and Digby, Prim Point, Nova Scotia.

a) Temperature:

Atmospheric temperatures display one of the lowest ranges of the Maritime Provinces with the warm season being cooler than other Maritime areas and the winter displaying slightly warmer temperatures. For purposes of this study the duration of the period of below freezing temperatures is most important. The mean daily temperature range is 7^{o}, with mean daily high and low temperatures for January of $-2^{o}C$ and $-13^{o}C$. The mean daily maximum temperature is seldom above $0^{o}C$ from late November to early February (Gates, 1973).

b) Precipitation:

Precipitation ranges from fog, mist and rain in summer, to snow and freezing rain in winter. Extremes of the snow season are the first of November to the last of April. Peak snowfall usually occurs in January with maximum snow cover in February and March (125-200 centimeters). Fog and mist occur 15 to 25% of the year with a peak number of days

with fog in July (Canadian Department of Transport, 1968).

c) Winds:

Wind patterns in the Bay of Fundy display marked seasonality. During the summer winds of low velocity (mean of 16 kilometers per hour) are predominant. They mostly display a south to southwesterly component. The winter season has a mean wind velocity of 22 kilometers per hour with a strong north to northwesterly component.

Although temperature and wind are the predominant controls of ice formation, these two variables are themselves influenced to a large extent by presence of sea ice. Pack ice or drift ice, which is always broken due to strong tidal currents (Hind, 1875; Knight and Dalrymple, 1976) builds up through January, reaching a maximum in late February. Where rock ledges are exposed at low tide and the intertidal foreshore is relatively steep, ice foot formation can reach heights of up to 9 meters with a width of approximately 5 meters. Winds influence transport of the pack ice and often drives it from one side of the bay to the other (Knight and Dalrymple, 1976).

1.4.6 Flora and Fauna

Flora and fauna play a very subtle geomorphic role on rocky coasts. Specialization and zonation are apparent in the study area due to microclimates, large tidal range and tidal scouring. Temperature limits the fauna range so that littoral organisms, elsewhere often important erosive agents of shore platforms, are here quite unimportant.

The large tidal range of the Bay of Fundy leads to a

relatively wide intertidal zone in most places. The intertidal or eulittoral zone may be subdivided into several zones according to the species of flora and fauna found within each of these divisions.

In areas where platforms are covered by the tide less than half the day (most often these are associated with low tide cliffs) barnacles are very abundant. Stephenson and Stephenson (1954) found barnacles were highly susceptible to ice action in the Bay of Fundy, but were easily restored during the spring months. Another organism common to the area is a species of limpet (Acmaea testudinalis testudinalis). It is found from below low water (on open rock surfaces) to upper parts of the intertidal zone (in pools or damp places). The most common type of bivalve found within the area is a species of mussel (Mytilus edulus). It is found attached above and below low tide cliffs and lower parts of exposed platforms. Several species of snails and small crustaceans are also found at various points in the study area but appear to be of minimal geomorphic significance.

The flora of the study area is restricted mainly to species of red and brown algae. Stephenson and Stephenson (1954) found Porphyra (a red algae) at lower levels of the intertidal zone. Emergent only at the low spring tides, and thus located at the very edge of the intertidal zone, are the species Rhodomenia (dulse) and Gigartina stillata. Both of these are harvested, one for human consumption, the second as a source of caragina (an additive for some dairy

products). Some brown algaes such as Fucus vesiculosis, F. edentatas and F. evanescens are commonly found above the red algaes (i.e. further shoreward). Almost, always submerged, but perhaps the most strategic from a geomorphological point of view, are several species of Laminaria (kelp) found there. Laminaria digitala and L. longicruris, sometimes up to a metre in length, often carry attached pieces of rock which may act as abrading tools.

1.4.7 Human Settlement

The area from Baxter's Harbour to Parker's Cove contains a number of small villages, none greater than a thousand in population. The major villages are Baxter's Harbour, Hall's Harbour, Harbourville, Canada Creek, Black Rock, Morden, Margaretville, Port George, Port Lorne, St. Croix, Hampton, Young's Cove and Parker's Cove. These were established as fishing villages 150 to 250 years ago.

Historically there has been a great deal of interaction between various neighbouring villages. Trails along the cliffs, coupled with boat travel, were utilized extensively. These trails have given way to modern highways along the top of North Mountain. However there is much less interaction between villages along the coast today. The villages are now more closely associated with the various neighbouring towns than with each other. This most probably is due to the development of good highways over the mountain together with the increasing need for villagers to seek employment in the towns.

Traditionally these villages depended on the sea and

allied marine trades for their economies. Most of the village men were engaged in nearshore fisheries. A secondary dependence was placed on forestry and agriculture. Improved technology led to diminishing fish stocks and forced most of the villagers to look towards the valley towns for employment. Due to poor soil, excessive drainage and short hours of sunlight, agriculture and forestry are largely impractical on an intensive basis.

Although the economic focus has shifted away from the sea to the larger towns, and forced many of the villagers to move, many of the villages are gaining in population. The area is becoming increasingly attractive for summer home development. Villages like Hall's Harbour, Margaretville and Hampton, have seen a vast increase in home building in the last 20 years. Areas such as Huntington Point and Turner Brook have only recently been extensively developed in terms of summer cottages. This leads to a highly seasonal population. For example, Hall's Harbour may have up to seventy families during the summer months, but this diminishes to about six families over the winter. Despite this seasonal aspect, the fact that the Bay of Fundy coast is becoming increasingly important from an economic standpoint is irrefutable.

A factor that cannot yet be properly assessed is the potential socio-economic effects on the area by the proposed Bay of Fundy tidal power development. The environmental effects of placing massive dams across the entrance to Chignecto Bay and Minas Basin will certainly not be

negligible. The potential social, environmental and economic impacts of such a development are currently the focus of a major interdisciplinary study. However, some insight with respect to potential impacts of such a development might be obtained from an examination of the suggested increase in tidal ranges which would result. Clark (1978) provides data suggesting that the tidal range at Saint John might increase by as much as 6 meters. Such a radical alteration to a natural system can only produce severe repercussions. As the influence of naturally increasing tidal range is dealt with in subsequent chapters some application of these findings will almost certainly be possible with respect to impacts of tidal power development.

1.5 Methods of Study

The collection, compilation and analyses of data for this study were divided into three phases;

a) Pre-field stage:

This stage consisted of defining the problem, hypothesis formulation and a search of the literature. At the same time logistical planning was made for the field season together with formulation of field methods.

b) Field-season stage:

Three distinct methods of data collection were used. The principal method involved field mapping and measurements. Location, extent and character of areas of cliff failure were mapped in detail. Profiles of the intertidal zone were surveyed at both ends of the study area, and in three intermediate coves. A series of iron stakes were

placed in order to monitor long term rates of retreat. A continuous water level recorder was placed in a well to monitor groundwater fluctuations in response to tidal oscillations. These were correlated with visual readings of tidal rise from a tidal gauge which was constructed in the intertidal zone adjacent to the water level recorder.

A second method of data collection involved personal interviews with long-term residents of various communities. This was done in order to obtain information on seasonality of cliff instability and to find local records or data on cliff retreat.

The last method of data collection involved a search of government, university and private records for possible information on events of local cliff retreat. This also served to avoid any duplication of research that could possibly arise. Newspaper articles and old journals were examined at the Public Archives of Nova Scotia in Halifax. Some data were provided on wharf construction by the appropriate government agencies. Unfortunately, despite a few notable exceptions, this method proved the least successful of those pursued.

c) Post field stage:

The period following data collection in the field was devoted to data analyses, air photo interpretation, and completion of the literature search. The field season led to several new perspectives on the problem and necessitated a more extensive literature search.

The primary task of data analyses was to determine the

frequency and magnitude of areas of cliff instability and their resultant debris masses for purposes of comparing various sections of coastline. Frequency distributions for both volume and areal extent were compared to surveyed profiles of the intertidal zone. The groundwater hydrographs were examined to determine lag times between high tide levels and high groundwater levels. This was then applied to Carr and Van der Kamp's (1969) relation for aquifer efficiency in an attempt to gain a crude insight into possible cleft water pressure within jointing patterns. Aquifer efficiency was then combined with records of seasonal precipitation, freeze-thaw days and streamflow. A correlation was attempted between these data and the seasonal distribution of cliff instability.

Air photo interpretation was undertaken to (1) complete field maps, (2) check on "ground-truthed" areas, (3) verify field measurements and, (4) most importantly, to estimate rates of cliff retreat. The first three procedures are self-evident. The fourth was attempted through the use of sequential air photography for five specific periods from 1930 to 1977 for the areas of Margaretville, Morden, Harbourville and Hall's Harbour.

The data treatment, together with air photo interpretation and a sound literature research, have served to give a comprehensive perspective on coastal erosion along the south coast of the Bay of Fundy. This perspective has evolved within the following framework:

i) model development;

Krumbein (1960) identified three prevailing problems in applying statistical methods to geological information. They include restrictions on sampling, the complexity and great number of variables and the high "noise-level" of some variables. These problems can be also expressed as probable bias in sampling, due either to inability to sample or over-abundance of a particular phenomenon obscuring more important phenomena. These are problems faced not only in data analyses, as Krumbein (1960) implies, but also in the organization and presentation of data.

Whitten (1964) suggests model formulation as a framework for structuring data in attempting to solve a particular problem. The present study adopts a simple process - response model which is initially conceptual in scope; that is, it infers a number of interrelationships between variables. A process - response model is envisaged as a specific set of process factors which are linked to specific morphological responses. It is suggested that such a framework will alleviate, as much as possible, the restrictions set out by Krumbein (1960).

This model strives to achieve a suitable combination of inductive and deductive approaches to problem solving. That is, it relies on common statistical methods to summarize and compare data (See Appendix III) in order to outline process directions. These in turn are substantiated as much as possible by field observations of functional relationships. In an effort to achieve such a combination, this model was based on Carson's (1969) outline of process -

response models. He suggested that three formulation steps are important. They include, (1) determination of processes and controlling variables, (2) evaluation of the nature of geometric change and, (3) extrapolation of this geometric change over longer time spans. In the past, according to Carson (1969), unduly great attention was placed on the third step, with lesser stress placed on the first. Inadequate attention was given the second step and thus no concrete way existed to relate a particular change in form to a particular process.

ii) model application;

Bearing Carson's (1969) stipulations in mind a model was developed which identified environmental controls (static variables) and process factors (external variables). This corresponds to Carson's (1969) first step. The resultant of the interaction of environmental controls and process factors can be related to Carson's (1969) second step. In other words the immediate resultant of the above combination leads to evaluation of geometric change at a single point in time. Carson's (1969) third step involves extrapolation of the immediate resultant and is expressed here as "products" and "feedback links". The complete model is outlined in Figure 1.3.

This process - response model relates particular processes and responses to the specific problem under consideration. In doing this it sets out the various steps by which this may be accomplished. Each segment or step in the model will relate to a specific chapter of this thesis.

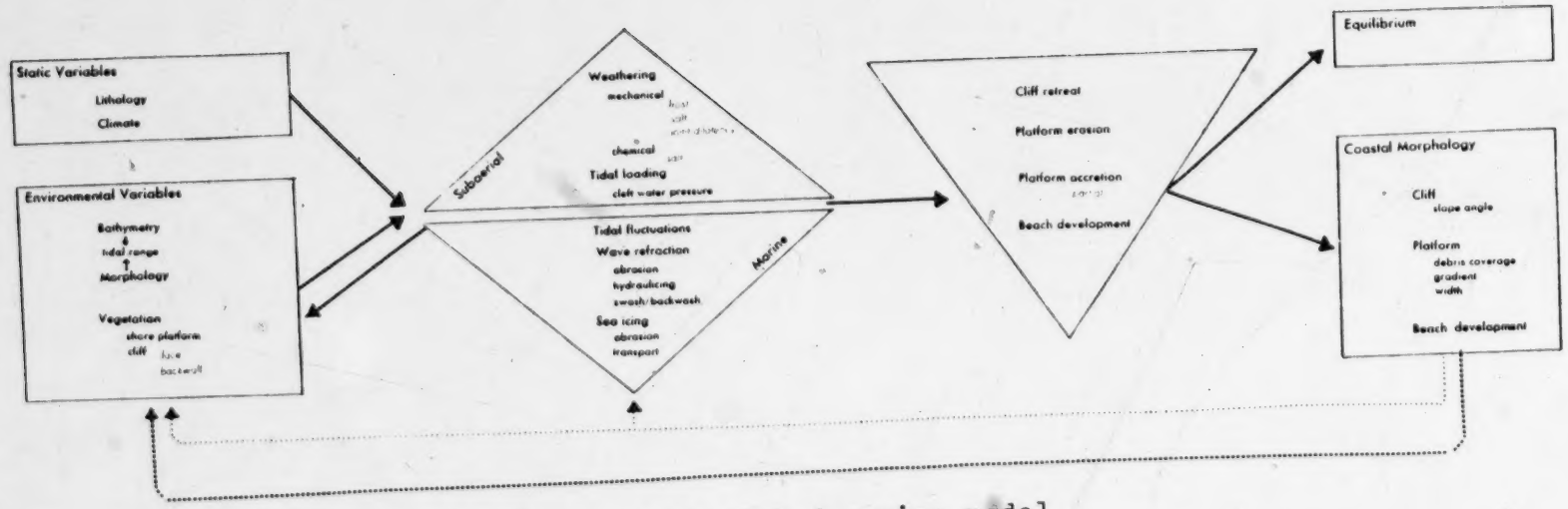


Figure 1.3 - Proposed coastal dynamics model.

Thus, chapter 2 will discuss environmental factors, chapter 3 process factors, chapter 4 the products, chapter 5 resultants and feedback links as a basis for conclusions. Therefore the overall objective of this study is to turn what is fundamentally a conceptual framework into something that may be quantitatively tested and in this way prove or disprove the study's initial hypothesis. Any subsequent application of this study should be based on the degree of success attained by this method.

CHAPTER II

ENVIRONMENTAL CONTROLS OF COASTAL DYNAMICS

2.1 Introduction

Coastal morphology and the processes which influence the physiography of the shore zone are governed by several types of controls. These controls can be roughly divided into two categories; static and environmental variables. Static variables are those that remain constant over a large time span (1000 years or more). On rock coasts the principal static variable is lithology of the bedrock units. A second static variable in this context (with a few notable exceptions) is climate. Environmental variables, on the other hand, are only constant, if at all, on a very much shorter term basis. Bathymetry, shoreline form and vegetation are examples of such variables, all of which may change on a yearly or shorter-term basis. The five variables discussed here all act to some extent as controls of the Bay of Fundy coastal zone.

2.2 Static Variables

2.2.1 Lithology

Lithology acts as a morphological control in two ways along the south coast, Bay of Fundy. The geologic composition and structure of the basalt tholeiites, which are common to the whole area, are the principal determinants of shoreline change.

a) Geologic composition:

As noted in Chapter 1, the bedrock of the south coast

is volcanic in origin and composed of a series of flows. Depending upon cliff height and locality, as many as six different flow units, or as few as one, may be distinguished at any given point. The thickness of these flow units, their number, the characteristics and positions of the contacts between the various units, and the presence or not of interflow sediments, have each been observed, at specific localities, to be linked to some form of coastal dynamics.

The thicknesses of the bottom two members and the top one, which are found throughout the study area, are relatively constant. The local flows, found in various combinations between those members, are of varying thickness often radically changing over a few meters along shore. As different flow units are often of differing composition, they may lead to differing levels of resistance to weathering processes. Coupled with this is the resultant position of the flow contacts relative to each other and to the beach elevation. These two components (thickness of flow units and positions of flow contacts) may act independently, or concomitantly, as a control of weathering efficiency. At Hall's Harbour the cliff face west of the wharf was observed to have a double series of notches. These notches may be explained as a result of the flow unit thickness; that is the vertical distance between the flow contacts being equal to the mean high water level and the level of influence of storm surges. West of Margaretville light, the northwest facing cliff displayed several, gently dipping

flow contacts. When these contacts reached either a critical angle (5^{o}) or a critical elevation (2 meters) with respect to the beach, instability of the cliff face was promoted. In the case of a critical angle, the upper flows were not provided with a suitable base and jointing and/or fracturing along the cliff face occurred. More common is the situation where the flow contact is at a critical elevation leading to wave undercutting, notching and cliff failure (See Figure 2.1).

Of limited significance, due to its confinement to only a few places within the study area, is the presence of interflow sediments. These were only noted at Chipman Brook (Figure 2.2) although Hudgins (1960) observed them at various locations between Chipman Brook and Harbourville. Hudgins (1960) suggests that these sediments may have been of fluvial or eolian origin. In any case they are of vastly differing resistance to weathering relative to the surrounding basalt members. As a result accentuated erosion of these deposits often occurs, with subsequent cliff face instability being promoted. A good example of this occurs at Chipman Brook.

b) Geologic structure:

The bottom and top volcanic flow units are conspicuously columnar jointed. Two significant effects of columnar jointing, in the context of controls of coastal processes, are the inherent weakening of the mechanical strength of the cliff faces and the development of very high secondary permeability, as compared to other flow units. These

Figure 2.1 a - Notch at The Cove, a result of flow contact being at a critical elevation with respect to marine processes. The bag seen to the lower right of the notch is approximately 0.3 m high.

Figure 2.1 b - Cliff failure, most probably a rockfall, east of Morden; a result of notching at the flow contact. Staff in center of debris accumulation is 2 m high.

Figure 2.2 - Interflow sediments at Chipman Brook. Staff is 2 m from base of picture.

Figure 2.3 - Cliff failure at Canada Creek occurring along the synclinal base of the top flow. Cliff height at this point is 24 m.

two factors are possibly the two most important controls of coastal processes along the south coast, Bay of Fundy.

Columnar jointed rock was found backing over 30% of the 165 debris accumulations examined within the study area. In many cases dipping contacts between the two top flows have led to structural weakening. Figure 2.3 shows an example of such an occurrence, at Canada Creek. The synclinal dips of the flow contact are displayed on the cliff face above the related debris accumulation.

High secondary permeability in such a situation is to be expected. Hudgins (1960), for a site south west of Victoria Harbour, noted continuous discharge of water from a position at the base of the columnar jointed member. During the course of this study, seepage from columnar jointed rock units was often noted. Although no direct observation of slope failure due to this cause alone was noted, several areas of recent failure were found with groundwater seepage present on the fall face (Figure 2.3). This evidence, coupled with accepted models of instability in rock masses (Carson and Kirkby, 1972), leads to the intuitive assumption that high secondary permeability due to columnar jointing is partly responsible, and probably of great importance, in the promotion of cliff failure.

Hudgins (1960) mapped eight areas between Baxter's Harbour and Parker's Cove displaying synclinal structure in the basalt flow units. These relatively gentle folds occur at Hall's Harbour (Figure 2.4), Huntington Point, Black Rock, Sweeney Point (west of Harbourville), Morden,

Figure 2.4 a - General view of The Cove. Top right of picture is Cranberry Point, 0.5 km east of Hall's Harbour, which is the trough line of a syncline. The arrow indicates the location of Figure 2.4 b.

Figure 2.4 b - Close-up of cliff face at The Cove, along east limb of syncline. Tripod in center left is approximately 1.5 meters high.

Margaretville, Port George and Port Lorne. A synclinal structure leads to limited cliff face exposure. Usually, only the top flow is exposed, leaving little opportunity for differential weathering and erosion. Thus areas of synclinal structure persist as minor promontories along an otherwise mostly regular coastline.

Two anticlines also occur in the study area, one at St. Croix Cove (Figure 2.5), the other at Hampton (Hudgins, 1960). These two anticlinal zones are the most significantly indented portions of the coastline. The anticlinal structures produce a greater cliff exposure, leading to an increased opportunity for differential weathering and erosion.

Figure 2.5 a - St. Croix Cove, an anticline. The arrow shows the site of Figure 2.5 b, the approximate location of the anticlinal crest line.

Figure 2.5 b - Close-up of cliff face at St. Croix Cove located in proximity of the anticlinal crest line. Note presence of large boulders. In contrast to synclinal coves, as in Figure 2.4 a, the major area of debris accumulation is along the west limb of the cove toward the point.

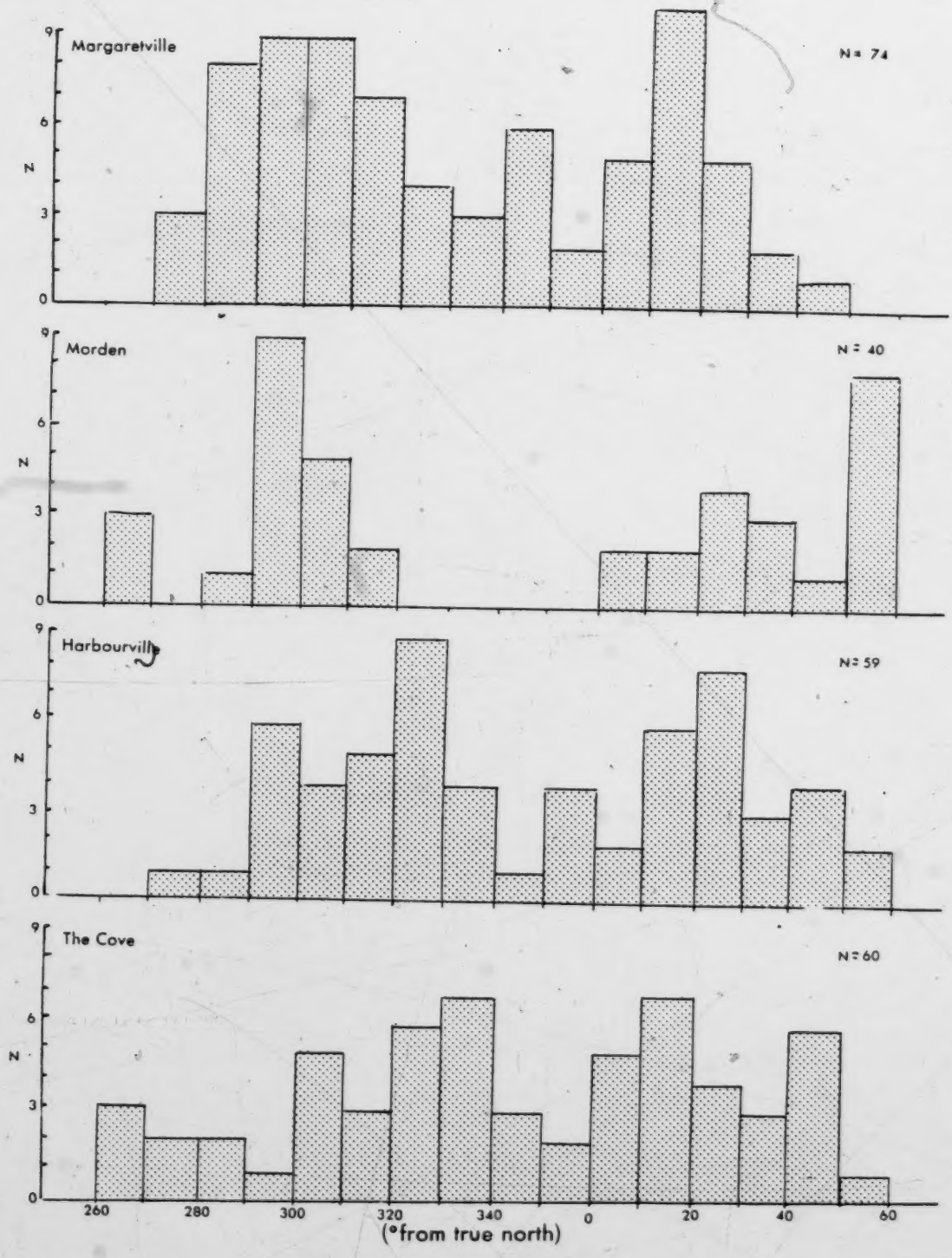
The system of primary and secondary joints which exist in the area was outlined in Chapter 1. Figure 2.6 shows the distribution of primary joint orientations as measured for the areas of Hall's Harbour, Harbourville, Morden and Margaretville. This distribution corroborates closely Hudgin's (1960) measurements. These joints are vertical and usually cut through more than one flow. The joint orientations usually parallel present fall faces within the coves, where measurements were made. This accounts for the series of offset blocks, mentioned in Chapter 1, which occur in the northeast quadrant of each of these four coves. Cliff retreat parallels these joints producing a step like regression in form, as the coves enlarge (Figure 2.7). This will be discussed more extensively in Chapter 3 when joint dilatency and frost wedging are examined in the context of erosional processes.

2.2.2 Climate

a) General considerations:

The greater Bay of Fundy area has undergone, at various times, severe climatic changes. However, within the time scale here (the last one thousand years), climate may be treated as a static variable. Thus, for purposes of this discussion, an area is being examined which is subject to pronounced climatic seasonality, moderated by maritime influences on temperature and precipitation.

Climate may act as a control of coastal processes in the context of a single climatic variable or as a combination of several. The role of freezing and freeze - thaw



Primary joint orientation for four coves
as determined from 1973 aerial photography

Figure 2.6

Figure 2.7 - Cliff face immediately east of Margaretville, showing offset development in cliff morphometry, according to orientation of primary joints.

processes is self-evident in that they may cause frost wedging, frost shattering and joint dilatency. Precipitation influences infiltration rates and in turn controls groundwater table locations. The role of groundwater as a process factor is examined in Chapter 3. Wind governs effective fetch, wave generation and ice transport. In order to fully understand the relative importance of each of these factors, it is necessary to examine their extent in the south coast area.

b) Data source:

Data concerning atmospheric temperature and precipitation were examined using records from the Digby Prim Point, Nova Scotia and Saint John, New Brunswick stations. The data were abstracted from the Atmospheric Environment Service and Department of Transport Monthly Record of Meteorological Observations in Canada. Some summary information was obtained from Gates (1973). Digby Prim Point is accepted as the most representative station for the study area (F. Amirault, pers. comm., 1978) due to its marine exposure as opposed to the more protected Saint John station. However, as Digby Prim Point is only a volunteer observation station, which was set up in 1965, Saint John must serve as a basis for any long term climatic analyses of the area. Saint John is also used as a data base for annual wind speeds and directions, as Digby Prim Point does not record wind characteristics.

c) Atmospheric temperature:

An examination of seasonal atmospheric temperature

patterns for the Bay of Fundy indicates that the spring season usually begins in mid to late April. For purposes of this discussion, spring is defined as the first fourteen day period where the number of days with atmospheric temperatures greater than freezing exceeds those with atmospheric temperatures less than freezing. This definition implies that the beginning of spring coincides with the spring thaw. Thus the time at which the mean soil temperature warms to above freezing must occur during this period.

The converse of the above is when mean soil temperature cools to below freezing, or the start of winter. Manipulating the above definition, it is suggested that the beginning of winter, for the Bay of Fundy area, usually occurs in late November or early December, producing a winter duration of about four and one half to five months.

A more detailed examination of atmospheric temperature for the months of December, January, February, March and April revealed the probability of a freeze thaw cycle (temperature fluctuating at or about $0^{o}C$ during a 24 hour period) in any one day of a month. This is shown in Table 2-1. In summary, the probability of freeze thaw increases toward spring from a low in February. What may be of more importance, however, is that the high probability of freeze thaw allows for few periods of prolonged freezing. The longest such period, between 1965-1977, was a sixteen day segment in January, 1970, with consistent sub-zero temperatures. Only three other comparable periods were noted for the twelve years of records at Digby Prim Point. The mean

TABLE 2-1

RECORDED OCCURRENCE OF FREEZE - THAW CYCLES FOR SPECIFIC MONTHS AT DIGBY PRIM POINT

	January	February	March	April	December
1965					14
1966	18	11	16	13	17
1967	23	14	18	17	21
1968	13	6	14	11	12
1969	16	21	21	12	17
1970	6	13	21	15	17
1971	13	12	28	12	15
1972	14	11	19	16	23
1973	16	11	22	11	15
1974	15	11	15	9	19
1975	17	11	18	10	16
1976	16	19	17	7	19
1977	11	16	20	14	
n	178	156	229	147	205
$\bar{X}$	14.8	13.0	19.1	12.3	17.1
s	3.93	4.05	3.75	2.93	3.06

length of continuous freezing is approximately 3 days.

d) Precipitation:

Table 2-2 lists monthly precipitation totals for Digby Prim Point for the months of December to May. These are the months which are indicated by Gates (1973) to have the most number of days in which significant precipitation occurred. (Gates, 1973, defines significant precipitation days as 24 hour periods with 0.1 inch or more precipitation). The calculated means tend to confirm Gates'(1973) Saint John data which pinpointed December and January as the highest precipitation months, with a tapering off towards the warmer months. He suggests that the total annual mean precipitation value for the south coast, Bay of Fundy is slightly more than 1200 millimeters. The data contained in Table 2-2 indicate a mean total, for the six month period under consideration, of 890 millimeters. Thus, if Gates' (1975) figure is to be accepted as applying to Digby Prim Point data, over 70% of the annual precipitation occurs during the period December to May.

In comparison with other regions of the Maritime Provinces the south coast, Bay of Fundy, apparently has among the highest precipitation values. Thus the study area is one of comparatively high precipitation, concentrated primarily in the months of December to May. As high rates of infiltration are often linked to mass movement events elsewhere, it might be concluded that this information is of significance here.

TABLE 2-2

SELECTED MONTHLY ATMOSPHERIC PRECIPITATION TOTALS (in millimetres) FOR DIGBY PRIM POINT

	Dec	Jan	Feb	Mar	Apr	May
1965	92.25					
1966	100.58	68.33	46.90	83.31	15.49	102.87
1967	274.57	110.24	128.78	132.84	61.21	130.30
1968	149.35	95.76	57.40	106.68	72.64	71.63
1969	125.73	125.22	56.39	73.91	99.31	104.14
1970	240.28	52.83	146.56	94.23	92.46	77.47
1971	112.52	121.44	97.79	85.85	63.25	105.41
1972	170.18	182.88	85.09	109.73	118.36	146.05
1973	206.50	119.38	147.07	133.60	71.37	127.76
1974	64.77	139.19	154.68	66.29	87.38	94.49
1975	148.59	168.40	53.09	137.66	36.58	169.20
1976	186.94	219.96	155.45	71.37	105.92	
$\bar{X}$	160	145.8	132.6	125.0	115.1	105.7
s	2.29	2.20	2.20	2.05	2.07	1.29

e) Wind:

Wind direction and velocity are of importance when considering effective fetch and hence wave generation and propogation. In addition it determines direction of transport of pack ice. In the Bay of Fundy, wind direction and velocity display marked seasonality. During the months of October to March wind velocity is at a maximum with a mean velocity of 20.1 kilometers per hour as compared to 16.8 kilometers per hour for the months of April to September (Gates, 1973). During the warmer months (April to September) wind direction is from the south - southwest while during the winter months the prevailing winds are from the north - northwest. The winds during both seasons display a westerly quadrant. However, winds of the winter months, although of much greater velocity, are dampened due to the smaller effective fetch. This also tends to lead to a concentration of pack ice along the south coast, which although limiting wave generation and activity may be important in terms of shore platform abrasive processes (Chapter 3).

A seasonal change exists in terms of effective fetch in the Bay of Fundy. This is directly related to the seasonal change in wind patterns. Effective fetch may be determined using a fetch width/fetch length ratio (Coastal Engineering Research Centre, 1966). The smaller this ratio the less is the effective fetch. Thus, as the wind direction shifts to the northwest coincident with the winter months, effective fetch is reduced. This is due to an

increase in fetch width and a decrease in fetch length.

2.3 Secondary Controls:

2.3.1 Bathymetry

It is important to consider the affects of tidal range when examining the affect of bathymetry in altering wave energy concentration. Since the alteration of approaching wave trains is dependent on depth to the ocean floor (wave steepening begins when depth to ocean bottom is equal to one half the wave length), vast changes in depth, such as those produced by tides, produce various refraction patterns with respect to tidal heights. In this presentation the two most extreme cases will be treated, offshore bathymetry when tides are low and intertidal bathymetry when tides are high.

a) Offshore bathymetry:

Bathymetry partly controls wave refraction. Given the limitations of existing bathymetric surveys along the south coast, Bay of Fundy, and given the change in effective fetch, with regards to seasons, any refraction diagrams must act as quite crude indicators of wave energy concentration. Refraction diagrams were constructed for the coves east of Margaretville, Morden, Harbourville and Hall's Harbour - The Cove. These are included as Figures 2.8a- 2.8d inclusive. Wave periodicity and height were obtained from data provided by the Canadian Hydrographic Survey (Appendix I). The Kb calculations (ratio of spacing between deep ocean orthogonals and near shore orthogonals) indicate higher values for the western part of the study

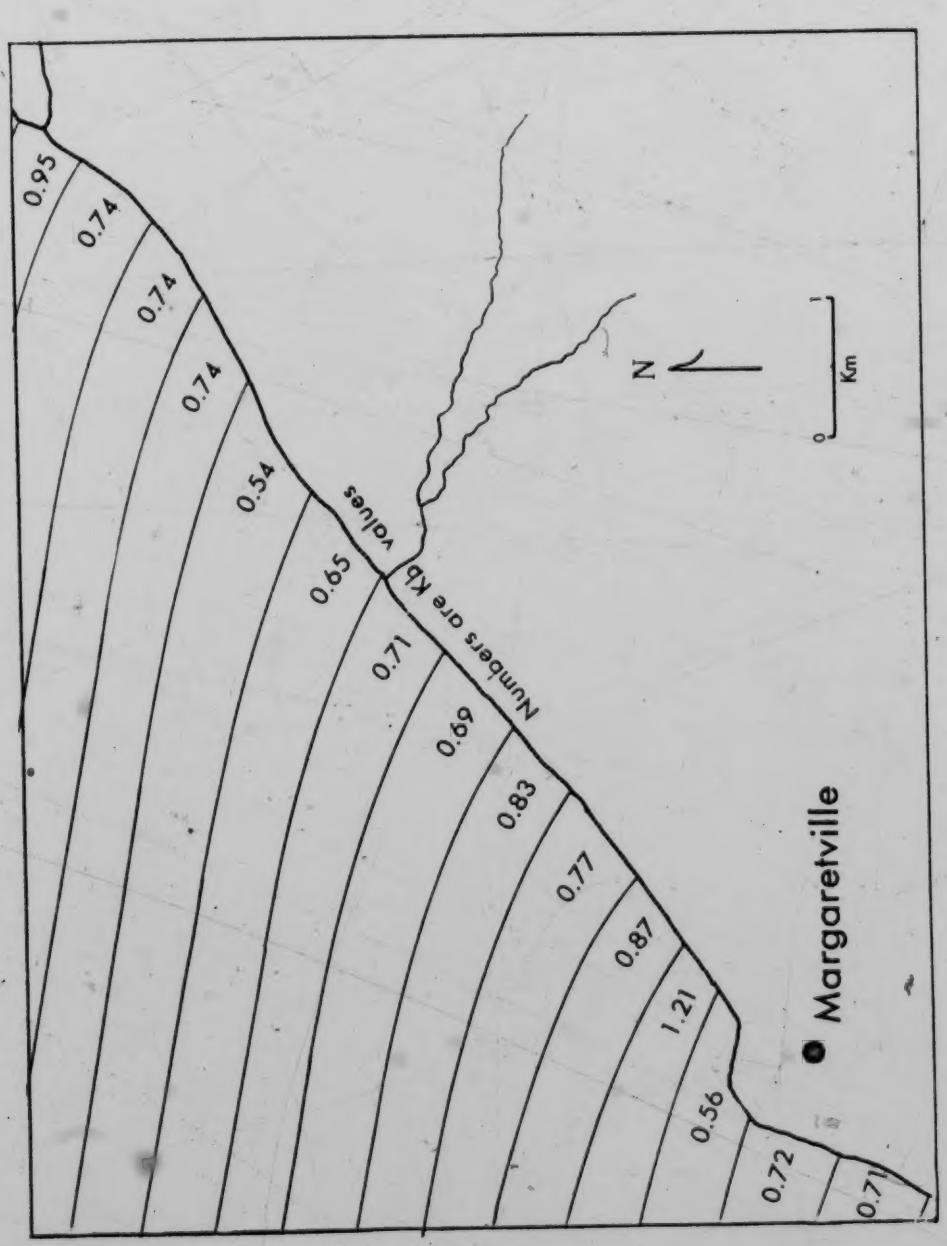


Figure 2.8 a - Refraction diagram for Margaretville.

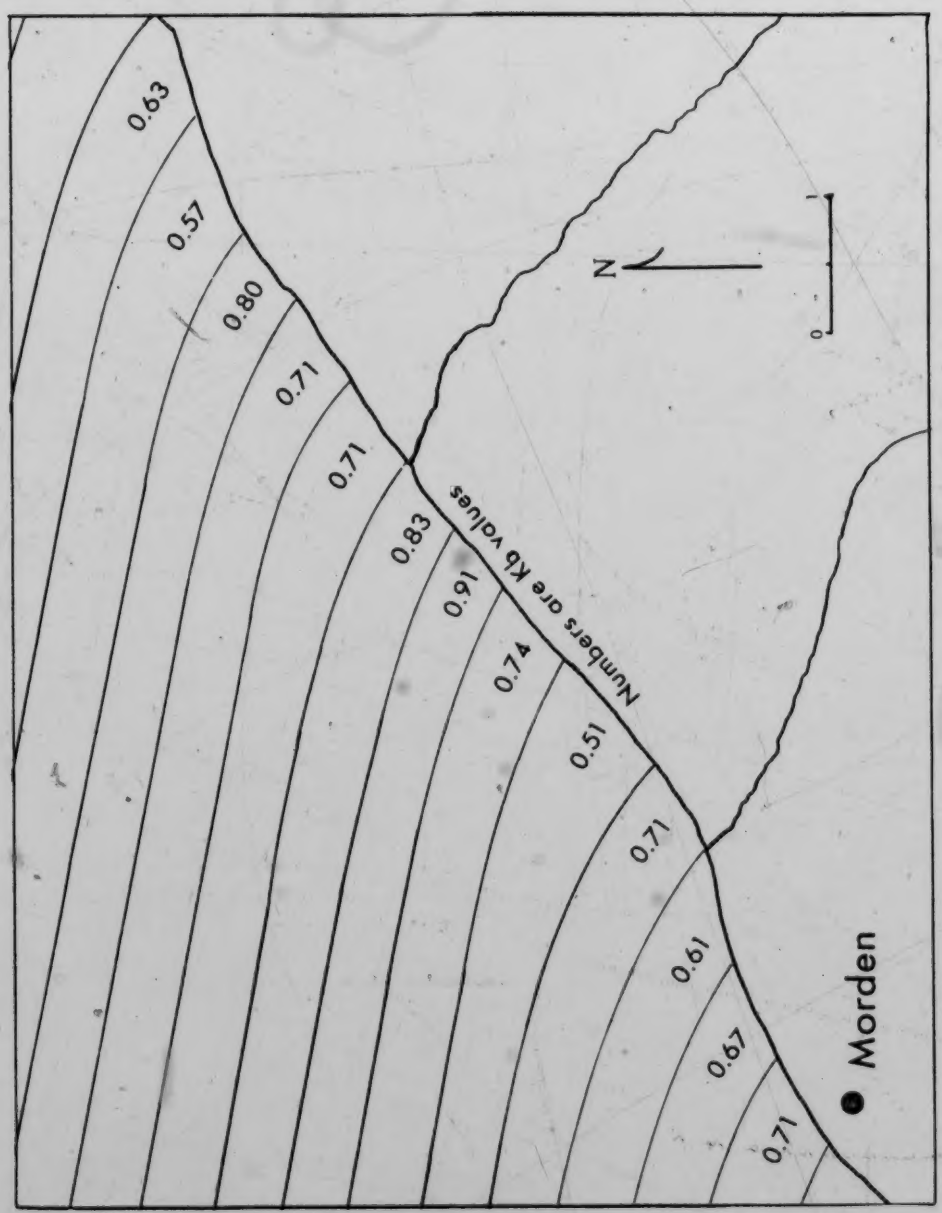


Figure 2.8 b - Refraction diagram for Morden.

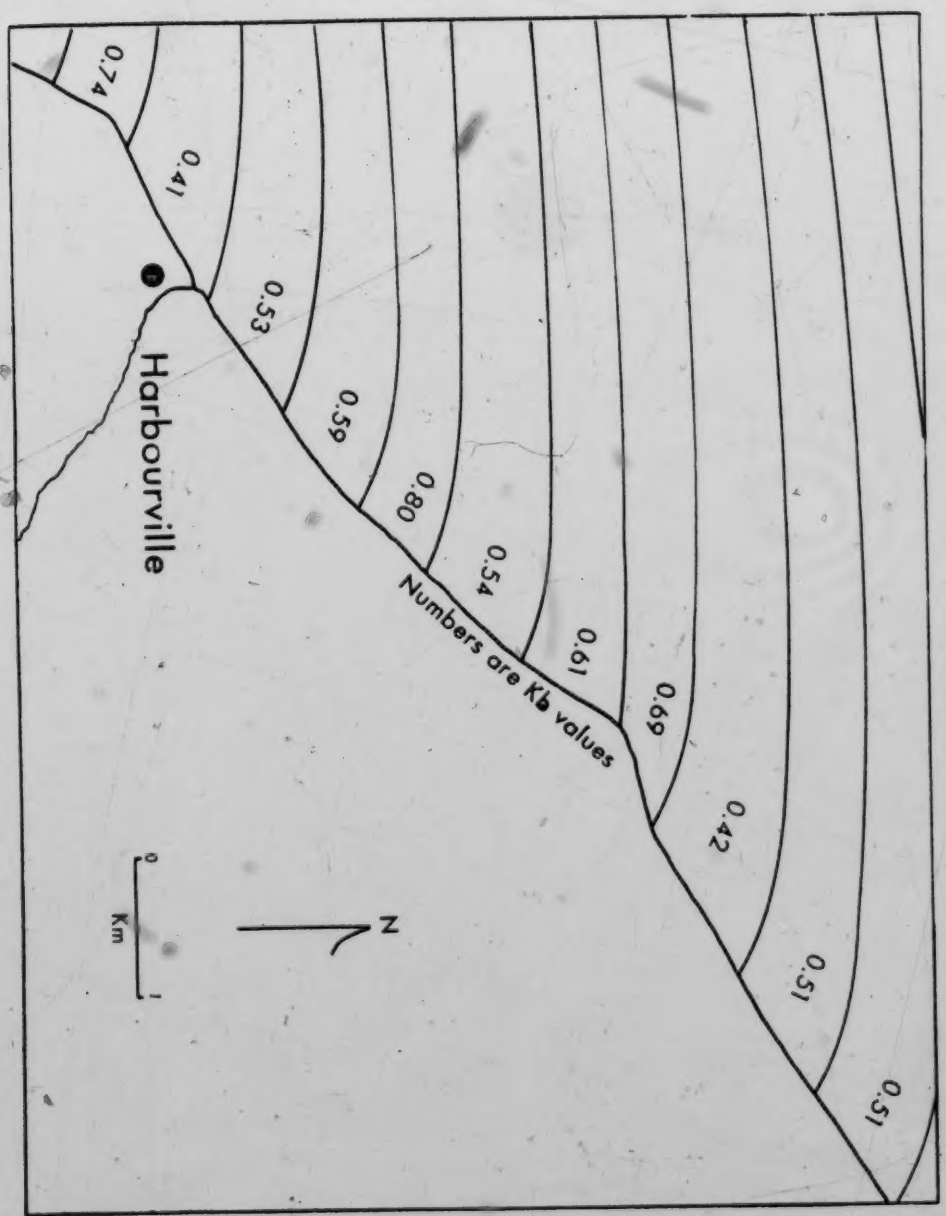


Figure 2.8 c - Refraction diagram for Harbourville.

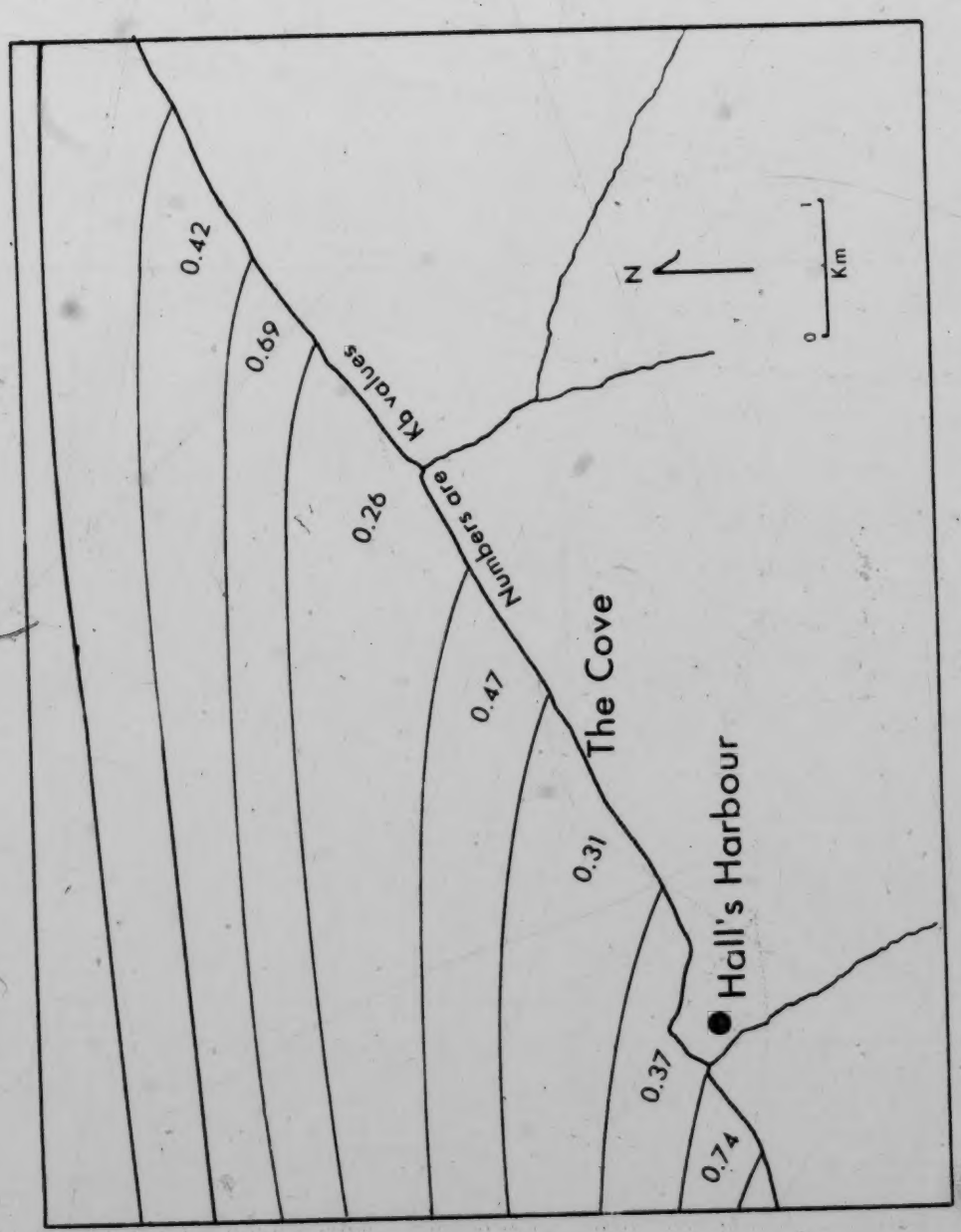


Figure 2.8 d - Refraction diagram for Hall's Harbour.

area signifying an increased wave energy concentration in that direction.

b) Intertidal bathymetry:

Offshore bathymetry is generally constant along the coast in terms of gradient (approximately 0.0091) and any consideration of refraction patterns is on a general basis. However, intertidal bathymetry is highly localized and depends on coastal morphology. Thus, the presence of storm ledges, low tide cliffs and differing platform gradients all help to determine refraction patterns and thus wave energy concentration during high water stages. Several examples of suggested products are presented in Chapter 3 where this process is examined in somewhat greater detail.

2.3.2 Shoreline Morphology

a) Gradient:

Gradient was examined in contrasted in three specific aspects, (1) in terms of platform gradient at specific sites along the coast, (2) in terms of beach gradient at sites of beach development or significant platform accretion and (3) on the east and west sides of projections normal to the backshore (most often wharves). This is discussed in terms of contemporary products in the final three sections of Chapter 4. With respect to gradient as an environmental control, it is discussed in Chapter 4 how platform gradient increases at sites in the eastern part of the study area as compared to western sites. A steeper platform may possibly allow closer proximity of the high water wave break points to the cliffs, thus increasing the

effectiveness of wave action as an erosional force. Trenhaile (1978), however, states that he has been unable to achieve any correlation to this end. The present study, also, cannot confirm or reject this possibility.

b) Cliffs:

Cliff height increases in an easterly direction. This is consistent with the fact that the elevation of the North Mountain dips to the west (Goldthwait, 1924). On a regional scale, cliff height was measured from aerial photos, with the aid of a parallax bar, for the cove areas of Margaretville, Morden, Harbourville and Hall's Harbour. (These measurements are included here as Appendix II). Relative cliff elevations decrease toward what Hudgins (1960) mapped as the synclinal axis present in each of these areas. Each cove shows an average relative decrease in cliff height as compared to the most adjacent easterly one. It is doubtful, though, that these measurements are of significance in regard to shoreline dynamics. On a much larger scale it is obvious that the presence of low cliffs (in the order of 1 - 2 meters height) as opposed to high cliffs (in the order of 20 - 30 meters in height) certainly does have a bearing on erosional rates. This can be seen by contrasting the regular, uniform coastline of Phinney's Cove with the highly indented features of the rugged relief in the St. Croix Cove area.

Cliffs which are mantled with till, such as at The Cove (east of Hall's Harbour), or banks composed outwash, such as the McNeily Brook area, also exert a control

over shore processes. They act as suppliers of sediment for longshore transport and lead to downbeach accretion, thus affording some protection for the related backshore areas. This is illustrated in the area west of Margaretville Light (Figure 2.9) which acts as a sediment accretion area for the McNeily delta longshore drift. Any erosion in the area appears to be the result of subaerial processes, or else a result of ancient marine action.

Figure 2.9a - Looking east toward Margaretville light. In right foreground is McNeily delta outwash, a source of longshore sediment.

Figure 2.9 b - Eastern boundary of accretion area at Margaretville. In background are the glacial outwash banks of the McNeily Brook area.

c) Coves and headlands:

Coves and headlands are often the product of lithological control as described in Section 2.1.2. However, by the mechanisms of positive feedback their formation may be accelerated. Once an indentation becomes significant along a coastal area a varying number of exposures to marine and subaerial forces becomes available. The extent to which a particular cove is developed controls the rate of change. Thus a well developed cove (by Bay of Fundy standards), such as that east of Hall's Harbour, has an eastern limb which is exposed to the direction of most effective fetch, while primary joints and tension cracks develop to an even greater degree.

Two significant types of headlands exist within the study area, semi-permanent headlands such as Margaretville Point, Sweeney Point or Cranberry Point, and temporary headlands as found along sections of cliff undergoing more or less parallel retreat. More prominent in terms of shoreline regularity are the semi-permanent headlands which are low, resistant, and as a result project up to 500 meters out from the adjacent shorelines. Temporary headlands take the form of sections of a cliff face being prepared for retreat (Figure 2.10) or sections which have undergone retreat, i.e. debris accumulations. Both types of headland afford protection to the immediate backshore while influencing the concentration of marine action, principally through wave refraction, on adjacent areas. In the cases of semi - permanent headlands this leads to cove formation

Figure 2.10 - Cliff face west of Morden. Temporary headland in left of picture is being prepared for retreat.

while in the case of temporary headlands (especially debris accumulations) recession of adjacent areas is accelerated, thereby contributing to the process of parallel retreat.

d) Drainage:

Surface runoff and drainage is not a particularly significant factor in coastal development of this area. It is an area of numerous small streams, regularly spaced, which drain very limited watershed areas. Since the last glaciation most of the streams have downcut to the underlying basalt and have usually adjusted to contemporary sea levels (i.e. kept pace with cliff recession). As a result these streams contribute little in the way of sediments and discharge and thus exert little influence on coastal processes along the south coast area.

2.3.3 Vegetation

Vegetation appears to play a very minor role in coastal processes along the study area. No significant correlation was found between vegetation distribution and areas of erosion. Aerial photograph interpretation was supplemented by ground verification in surveying the vegetation of the area. This information was applied to maps showing areas of contemporary slope stability and areas which presently or recently have undergone cliff retreat. Thus, the present discussion of vegetation must be limited to a few brief qualitative statements.

Goldthwait (1924) discusses "devils aprons" which consist of large amounts of kelp to which rock fragments are attached. He suggests that the kelp buoys the rocks which

may then act as abrading agents along the Nova Scotia coast. King (1972) suggests that along some rock coasts rocks weighing up to 9.1 kilograms are attached to 90% of the kelp. No observations of this phenomenon were noted within the study area. This could be due to two factors, first the low occurrence of kelp in the Bay of Fundy and secondly the lithology of shore platforms being inconducive to such a process.

Vegetation may act in some cases as a retardent of erosional processes. In the intertidal zone several species form a thick mat which retards erosion of the platform and at certain tidal stages may inhibit the movement of cobbles to the backshore. Above the cliffs, vegetation may act as an interceptor of rainfall that otherwise might penetrate into joints and tension cracks leading to toppling. At the same time, where soil depth is significant, well developed vegetation serves to anchor the soil and prevent soil creep or slumpage although forest cover may also act as an agent of mechanical erosion through root wedging.

CHAPTER III

PROCESS FACTORS

3.1 Introduction

Employing a systems approach, it is possible to make the statement:

Contemporary Products = f (Environmental Controls + Process Factors) where contemporary products comprise the state of the shore zone at any given time. The role of environmental controls, which were examined in the previous chapter, is as the primary determinant of the extent or scale of ongoing coastal processes. However, environmental controls alone, do not produce a dynamic situation. A threshold factor, or series of factors, is needed to initiate specific processes, hence the "process factors" part of the functional statement.

Process factors in the coastal zone involve complex interactions of sub-aerial and marine components. Because of the interdependency of these two components, it is impossible to identify single factors as being responsible for a particular process or morphological unit. This view is not necessarily a commonly held one. There has been a traditional emphasis on the marine component in coastal processes while the sub-aerial component has often been ignored (e.g. Steers, 1953, Sunamara, 1973). Thus one encounters references in literature to such things as "wave - cut terraces" instead of shore platforms. All too often, even in contemporary research, this approach is clung to;

for example: "... As you are well aware, it [cliff erosion in the Bay of Fundy] is a response of sea level rise and the effects of this and wave erosion, during high spring tides, to erode the cliff foot ..." (C.L. Amos, pers. comm., 1978)

For this study, sub-aerial processes have been divided into two principal categories, weathering and internal stresses. Weathering processes which have been examined along the Bay of Fundy south coast are principally mechanical, and include frost wedging / shattering, salt weathering and organic weathering. Internal processes involve discussion of causes and effects of cleft water pressure, joint dilatency, and chemical weathering of joints. Marine processes include the most commonly discussed forms of wave influence, such as refraction, abrasion, swash / backwash and hydraulicing, plus the effects of tidal fluctuations on coastal dynamics and the significance of sea ice with respect to the Bay of Fundy.

3.2 The Sub-aerial Component

3.2.1 Weathering

a) Frost weathering:

Discussions with a number of study area residents, in particular several fishermen, revealed a general concensus that cliff failure displays marked seasonality. Except for one fall that occurred in late December (M. Mosher, pers. comm., 1978) all major cliff erosion events occurred in the spring months (late March, to mid - May). This is in agreement with the observations made by Bjerrum and Jorstaad

(1957) in Norway and Rapp (1960a) in Sweden. Their conclusions suggest frost and freeze - related processes to be the main cause of slope failure in their study areas. It is not unreasonable to stress the significance of these processes in the Bay of Fundy. Three levels of mechanical weathering processes (relative to sizes of resultant products) may be distinguished for the south coast, Bay of Fundy. All of them bear characteristics that very possibly could be attributed to freeze - related processes. These levels are classified as (1) micro scale, (2) meso scale and (3) macro scale.

(1) micro scale action;

The cliff face west of Margaretville and the most southerly part of The Cove are among areas within the study area where exfoliation is characterized by a veneer of weathered particles which may be easily stripped from the cliff face (Figure 3.1). In both areas the cliff face, where this weathering has occurred, is of massive lithology with predominant amygdaloidal features. The amygdules are generally in the order of 1 to 2 millimeters in diameter although some range up to 2 centimeters in diameter. The exposure of these amygdules on the cliff face accentuates surface areas on which frost related processes may work. They also are semi - enclosed which potentially allows high pressures to develop, within the features, during periods of rapid freezing. Subsequent rapid freezing and thawing act to weaken the immediate surface zone of the cliff face. The frequencies of rapid freezing and thawing are high in

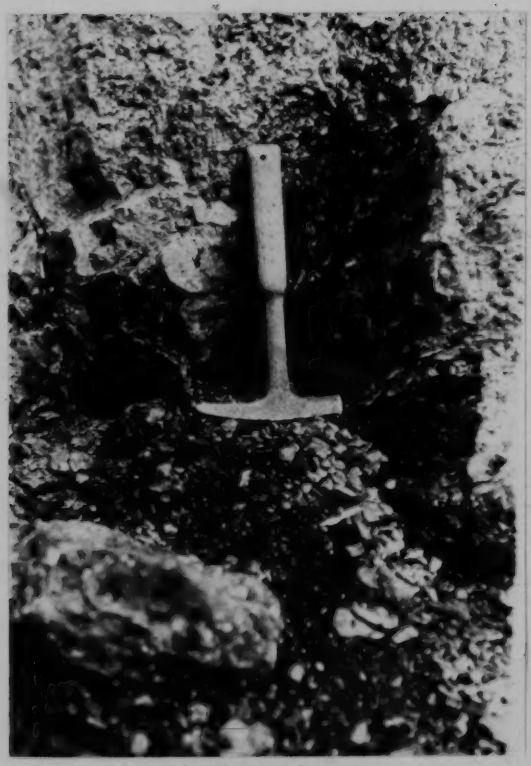


Figure 3.1 - Close-up of the cliff face located 0.5 km west of Margaretville. Exfoliation is characterized by a layer of weathered particles up to depths of 10 cm as indicated by area chipped out with the hammer. Figure 3.5 indicates the location of this site.

this area, especially during periods of heavy precipitation (see Chapter 2).

(2) meso scale action;

Much of the cliffed part of the study area is characterized by small accumulations of talus. The constituent fragments of rock are sharply angular and the talus can usually be traced to the upper limits of the cliff face. The mean diameter of the fragments appears to be approximately 10 to 20 centimeters. It is suggested that these accumulations may be mainly the products of frost shattering. The angularity and size of the fragments lead to this conclusion. This form of erosion originates near the top of the cliffs, where saturation is common and in rock which is often highly jointed on a small scale (as at Margaretville, Figure 3.2). Wiman (1963) has shown that rates of frost shattering are directly related to the number of planes of weakness present. Thus the high number of planes of weakness, together with climatic conditions, indicate a high probability of frost shattering taking place along upper cliff face surfaces.

(3) macro scale action;

Frost wedging as a form of joint dilatency may also be a significant factor. Open, exposed tension cracks have been noted in the study area. These provide fissures capable of retaining large amounts of moisture. Their exposed nature suggests that diurnal freeze-thaw cycles in the atmosphere may also be effective in this case. Repeated freezing and thawing dilates the joints, by small amounts,

Figure 3.2 - Cliff face west of Margaretville. Debris in foreground has originated from upper part of low cliff, most probably as a result of frost action.

until a threshold condition is reached and the slab falls. The threshold condition which determines if failure occurs, may in such cases be defined as when the center of gravity of the block or slab overhangs the pivot point of that same rock unit.

This same process also may be significant in dilatency of primary columnar structures, such as in the case of Canada Creek (Figure 2.3), Victoria Harbour fall (Figure 3.3) or the block rotation observed at Black Rock Light (Figure 3.4). The remnants at Black Rock seem to have rotated outward perfectly as though they had been overturned, while at the same time originating from an area of relatively low backshore relief. In this case frost wedging seems to be the most probable cause of retreat. Similar situations occur at Long Beach. This may in fact be the most important way that the characteristically, columnar jointed, ledge formations along the coast undergo erosion.

However, the work of De Freitas and Watters (1973) suggests possible alternative mechanism whereby a failure, such as that at Black Rock, may take place. They suggest that toppling (a form of cliff retreat that is suggested here to be somewhat analagous to slab failure) may take place where the angle of flow contact dip is less then that required for sliding. This, according to their work, can only happen in most cases, when the toe block of the slope unit is removed. This comparitively stable toe block retards movement in the back slope. It may be removed by erosion or sliding. For the Black Rock case it might be argued that, once marine erosion removed the toe block, the back slope became prone to failure despite the fact it rested on a base displaying a very low seaward dip. This is the same process as De Freitas and Watters (1973) outlined for the field example at Gowlish cliff in North Devon.

b) Salt weathering:

A form of weathering, in the coastal zone, of possible significance is salt weathering. It generally takes the mechanical form of salt wedging or salt crystallization, but may also include some chemical processes.

The exfoliation and granular disintegration observed at Margaretville may be a product of salt weathering instead of or in combination with, frost processes. The cliff face may be saturated with sea spray during high tide, and then, during periods when low water coincides with the afternoon, be exposed to high rates of insolation due to the westerly orientation of the cliff face (allowing a suitable angle of incidence) plus its highly absorbant (in terms of insolation) dark colour. However, the fact that

Figure 3.3 - Columnar structure in Victoria Harbour area. Such well developed structure is especially prone to dilatency related processes.

Figure 3.4 - Toppling in ledge formation west of Black Rock light, most probably a result of frost wedging.

the northeast facing section of the erosion pocket examined (Figures 3.5 and 3.6) displays a greater thickness of exfoliating material than that of the northwest facing cliff face, suggests either that frost related processes are of greater significance due to the low exposure of this section to the sun or that there is a higher rate of removal of weathered products on the northeast limb due to its exposure to longshore processes.

Figures 3.7 a and b show an exposed storm ledge at Long Beach. It was discussed above how an area just to the east of this feature may be undergoing frost wedging. At the micro scale, though, it is possible that the rounding of the tops of the basalt columns may be a form of spheroidal weathering caused by salt action. The texture of the ledge, shown in Figure 3.7a, is highly pock - marked and abrasive to the touch. Here the factors of maximum exposure to all angles of sun incidence, together with the dark rock colour, may be of greater importance than on exposed cliff faces. Therefore salt wedging and crystallization may be of greater importance in such cases.

c) Joint dilatency:

Due to the elastic nature of the basalt any movement of a block, column or slab should only be temporary if the centre of gravity has not been disturbed. The temporarily displaced block, column or slab section of the cliff would be expected to return to its original position. However the process of joint dilatency may often act to offset the elastic properties of the rock. One form of joint

Figure 3.5 - Erosion pocket west of Margaretville. Arrow indicates site of Figure 3.1. Staff is 2 m high.

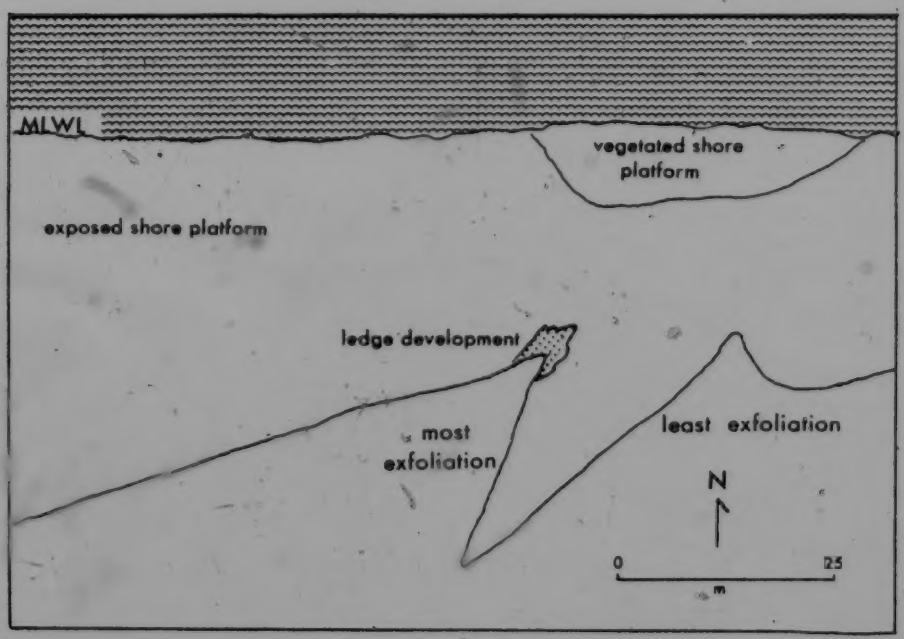


Figure 3.6 - Diagram of Margaretville erosion pocket.

Figure 3.7 a - Weathered storm ledge at Long Beach.

Figure 3.7 b - Close-up of Long Beach ledge showing resultant of salt weathering.

dilatency already discussed is frost wedging. Another common mechanism of joint dilatency is the falling of soil, overburden and organic material into the joint during its expansion. Although it is impossible to estimate the significance of this process it may be of particular importance in the case of slab failure. Figure 3.8 shows an example where joint dilatency may have become the prime subaerial factor in governing the process of slab failure.

3.2.2 Internal Factors

a) Tension cracks:

Unloading or release of material from the fall face exposes a new area of rock which immediately becomes the new fall face. This often results in the formation of dilatation joints. Carson and Kirkby (1972) state that this release of material corresponds to the transformation of the new wall or fall face from a passive state of stress, where maximum pressure was achieved while restrained by the material in front, to an active state of stress where confining pressure forces have reached a minimum. The relaxation of pressure leads to a general relaxation along the surface zone. Loss of cohesion along the joint planes seems to be the inevitable result, providing for a continuous joint to cut across various joint planes parallel with the existing fall face. Carson and Kirkby (1972) term these dilatation joints, pressure release joints or tension cracks.

Several such tension cracks were observed within the study area. Some have already been illustrated in

Figure 3.8 - Headland east of Harbourville. Joint dilatency can be observed to left of staff.

connection with other topics (e.g. Figure 2.10). Figure 3.9 shows the preliminary stages of tension crack development at The Cove. Figure 3.10 is a view of the cliff face with the arrows indicating east and west extremities of the tension crack. Monitoring stakes were placed two meters apart on opposite sides of the tension crack. Table 3-1 summarizes the results of movement measurements to date. The two data points illustrate the possible exponential widening of the crack, a situation outlined by Terzhagi (1950) and, Carson and Kirkby (1972), among others.

b) Cleft water pressure:

Terzhagi (1950, 1962) uses the term cleft water pressure to describe the pressure that is developed within joints close to the surface zone of the cliff face, through fluctuations in groundwater levels. Terzhagi (1962), Carson and Kirkby (1972) and Wyrwoll (1977) all suggest that the zone near the surface of the cliff face is of higher secondary permeability than that immediately back of this zone. This surface zone could be defined as abc in Figure 3.11. The cliffs along the south coast, Bay of Fundy, usually do exhibit high secondary permeability due to the columnar structure and secondary jointing. Intuitively one can visualize the greater permeability that takes place as a result of the pressure release described in Section a, above.

It is suggested that during wet periods the water table is at the level ad, (Figure 3.11). During periods of high infiltration, through runoff and snowmelt, the water table might

Figure 3.9 - Tension crack development at The Cove. See Table 3-1 for observed rates of widening for this feature.

Figure 3.10 - East and west extremities of tension crack observed in Figure 3.9. This area is located at the site of the largest (in terms of areal extent and volume) debris accumulation within the study area.

TABLE 3-1

DISTANCE BETWEEN TWO MONITORING STAKES PLACED ON OPPOSITE SIDES OF TENSION CRACK AT THE COVE. (MEASURED BY JOHN NEVILLE, HALL'S HARBOUR).

Date	Distance
July 24, 1978	2.0 m
October 15, 1978	2.10 m
December 25, 1978	2.29 m

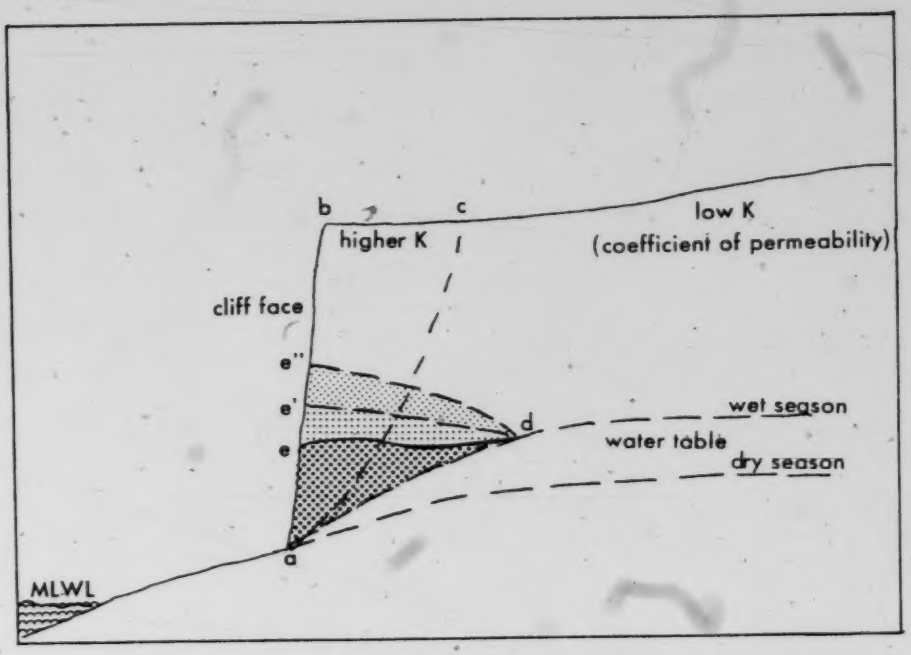


Figure 3.11 - Suggested fluctuations of the water table leading to cleft water pressures. These fluctuations are in response to various climatic variables (adapted and modified from Terzhagi, 1962).

rise to ed. The cliff face is often frozen along the predominantly north facing cliffs of the study area in the early spring. The joints and cracks, which would normally allow groundwater seepage, are then plugged which may induce the zone of saturation to rise to e'd. In the Bay of Fundy, a very significant factor, which could lead to a further bulge in the water table, is that of tidal range influences. In Figure 3.11 this factor is indicated by the line e"d.

In an effort to measure the effect of tidal changes on groundwater level, a continuous water level recorder was installed in a drilled well on the Phillip Neville property in Hall's Harbour for the period June 20, 1978 to July 25, 1978. At the same time a standard rain guage was placed approximately 20 meters from the well in an exposed area. Figure 3.12a shows the record of change in water level during an 84 hour period beginning on July 17, 1978 at 1000 hours A.S.T. Figure 3.12b shows measured amounts of precipitation for that period and Figure 3.12c shows times of tidal extremes during the same period. On the basis of these data, the change in water level due to infiltration of precipitation is greater (by a factor of 10) than the change due to tidal influence. Also, the lag time between peak influence and time of event (tide or precipitation) is approximately seven times greater for precipitation as opposed to tidal range.

Lag time with respect to tides, increases with distance to shore (Carr and Van der Kamp, 1970; Hennigar, 1976).

However, lag time with respect to precipitation, as experienced in the Hall's Harbour observation well, is a function of topography, groundwater flow patterns and center of precipitation. It was probably at a minimum for the one recorded event (Figure 3.12). Thus in terms of lag time, tidal effects are much more significant than precipitation effects. They display strong periodicity and thus may promote rock fatigue, through the diurnal fluctuations of de".

It may be that de" (Figure 3.11) is subject to a much more varied range of fluctuations as compared to de'. This is because groundwater fluctuations due to tidal loading may be highly variable within localized areas. Terzhagi (1962) suggests that this is due to the variable nature of secondary permeability. Thus adjacent observation wells may record vastly differing values in change of head. This may be the case in Hall's Harbour where two community owned wells on the east side of the harbour are subject to changes of head of up to 5 meters (H. Mosher, pers. comm., 1978). The neighbouring community of Baxter's Harbour is the site of one drilled well with fluctuations reported as high as 20 meters (C. Chapman, pers. comm., 1978). Carr and Van der Kamp (1970) recorded changes in head of up to 2.5 meters in highly fractured, impervious sandstone near Charlottetown, Prince Edward Island. Hennigar (1976) recorded similar observations in an unconfined sand aquifer on Sable Island, Nova Scotia. It should be noted that Sable Island and Charlottetown are both in areas of very low tidal range as compared to the Bay of Fundy.

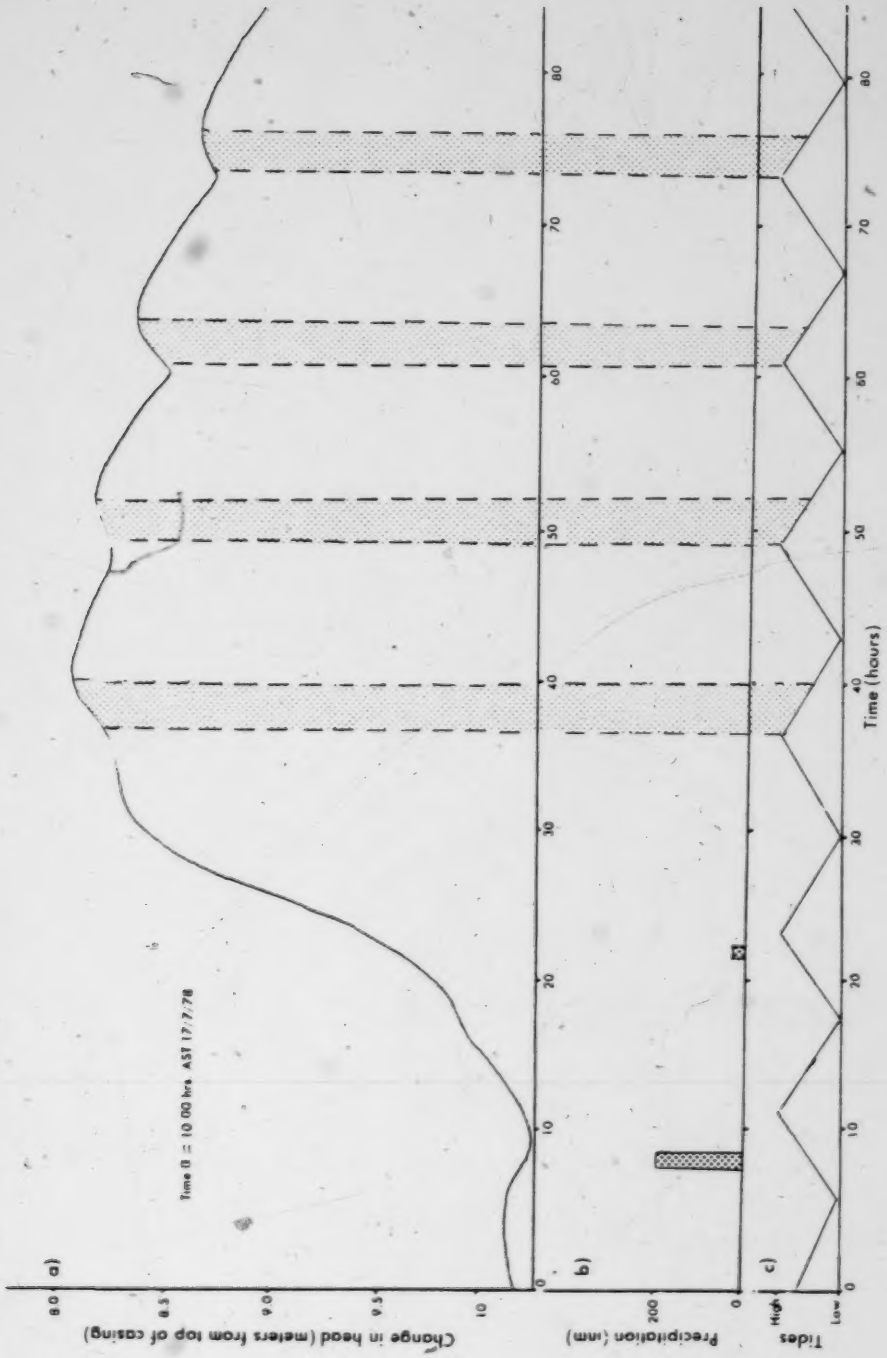


Figure 3.12 a) Hydrograph of groundwater fluctuations b) Precipitation totals, c) Tidal fluctuations; all for an 84 hour period at Hall's Harbour.

Increased height of the water table leads to increased height of a column of water within a joint. Terzhagi (1962) suggests that the pressure exerted on the walls of a joint is equal to the unit weight of the water times the height to which the water column rises. The cleft water pressure would thus be zero at the top of the water table and reach its maximum at the bottom of the joint. Carson and Kirkby (1972) relate failure to the degree of "intact area along the potential sliding surface", where this intact area pertains to the areas of rock not continuously joined by fractures or joint planes. Once this intact area is reduced to a minimum critical value, shear stress becomes greater than internal shear strength of the rock, plus the frictional resistance along the plane of slip. Cleft water pressure is one mechanism whereby the internal shear strength might be reduced and failure of the surface zone occur.

Cleft water pressure may be one of the prime process factors in cliff retreat within the study area. The evidence for this includes the seasonality factor (the most extreme pressures would occur in the spring), the high number of slab failures initiated by tension crack development and the evidence that tidal range effects changes in the water table.

Cleft water pressure may, however, be only one of the potential products of high runoff, spring melt, ice plugged joints and tidal loading. The effect of frost as a form of joint dilatency has already been examined. A factor,

discussed in the next section, is the possibility of chemical weathering being promoted within the joints, due to runoff or spring snowmelt, leading to progressive weakening of the cohesion between joints. Also highly probable is the fatigue effect produced within the rock by episodic changes in water table levels and the more periodic effects of tidal loading.

c) Chemical weathering

The effects of chemical weathering on a cliff face or on an exposed shore platform are extremely difficult to assess. Chemical weathering may be of more importance as an internal weakening agent. It is suggested here that rain water and surface runoff act to infiltrate through the joint systems, promote chemical change and subsequently weaken the internal cohesion of the surface zone of the cliff. Evidence that chemical weathering does take place along joint planes is fairly common for North Mountain basalts. White staining, which may have resulted from precipitates of silicate related minerals over an extremely lengthy time period, is often seen on the cliff face where recent separation seems to have taken place along the joint plane. Greenish - yellow stains, which are characteristic of limonite deposits are very common. Reddish colours may also indicate the presence of limonite or products of oxidation. As these are all visible on fresh cliff faces in the study area, as well as on cliffs that have been exposed for a period of time, it is evident that precipitates from internal chemical weathering must be well developed.

Although the precipitates in this case act partly as a form of cementation, the important factor to consider is that chemical changes are taking place within local rocks and not just at their surfaces. Such chemical changes must indicate gradual weakening of rock strengths.

3.3 Marine Factors

3.3.1 Tidal Fluctuations

The great tidal range within the Bay of Fundy means that, for the majority of locations within the study area, part of the cliffs are submerged to a certain extent, twice daily. Trenhaile (1978) examined effects of tidal action in the Gaspe, Quebec, area and found that the maximum duration of still water level was at a height just above the mid-tide level. This coincides with the area of maximum storm wave activity, an area which delimits the zone of maximum abrasive activity on the cliff face. This example serves to illustrate that the extent of tidal action is one major determinant of the extent of marine action.

In the following sections various processes are discussed, all of which are partly governed by the degree of tidal range present. Refraction and diffraction depend partly on water depth which obviously depends on the tide. An increase in tidal range leads to a greater area of cliff face over which abrasion may take place. In turn, abrasion often leads to basal notching of the cliff, which if enlarged sufficiently, may promote cliff failure through hydraulic compression of air during periods of high tide. A tidal range increase leads to an increase in the horizontal

area over which swash - backwash processes may occur. Finally, tidal currents may directly influence the transport of offshore sediment and, in winter, sea ice.

3.3.2 Waves

Regardless of tidal level, waves in the Bay of Fundy play a significant role in coastal processes. At higher tidal levels the cliff face is affected, most commonly producing basal notching. At lower levels the shore platform, low tide cliffs and beach cover where applicable, are affected. Topics of consideration for the subject of wave related processes include refraction, diffraction, abrasion, hydraulicing on the cliff face, swash - backwash, and longshore sediment transport.

a) Refraction, diffraction:

Chapter 2 introduced the concept of wave refraction as it relates to the general bathymetric character of the Bay of Fundy. Wave refraction leads to the concentration of wave energy along certain coastal segments and its diminution for others. On a regional scale, as noted in Chapter 2, wave energy is concentrated with respect to the coves of the study area. On a local scale the results of wave refraction can be observed as an expression of differential erosion adjacent to storm ledges or low tide cliffs. Figure 3.13 depicts an example of differential erosion resulting from wave refraction at Sheffield Vault. Figure 3.14 is an approximate refraction diagram of the same area. The diagram indicates a concentration of wave energy at A and its diminution at B. This would indicate a higher rate of

Figure 3.13 - Differential erosion of cliff face as a result of ledge development in the intertidal zone at Sheffield Vault.

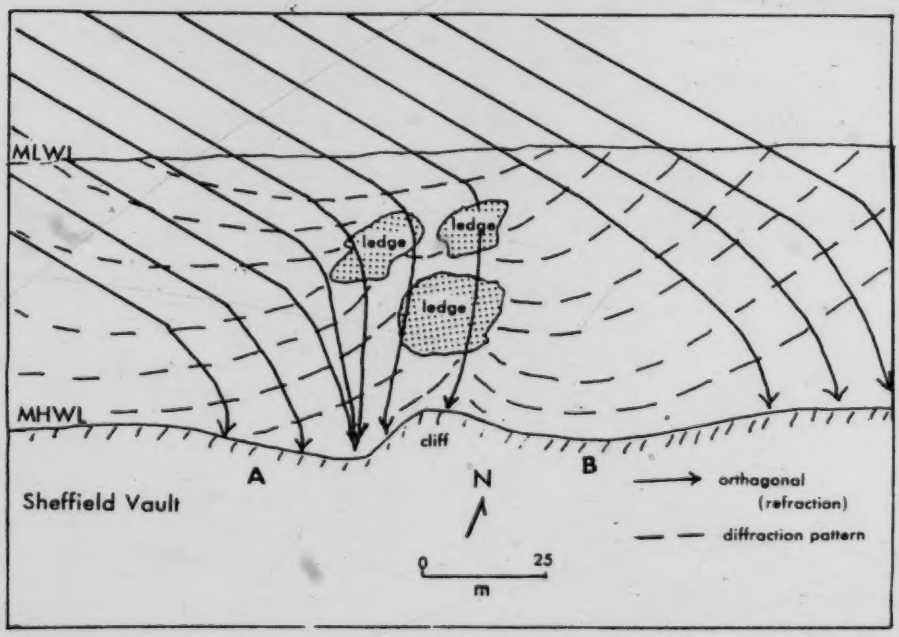


Figure 3.14 - Diagram of possible refraction and diffraction arising from foreshore ledge development at Sheffield Vault.

past and potential erosion at A, compared to B.

From Figure 3.14 differential erosion is also noted at B, although not to the degree shown at A. As fetch is predominant from the northwest this would tend to exclude refraction as a cause of this erosion. It is suggested here that wave diffraction, the lateral transfer of energy along a wave train, serves to concentrate wave energy at point B.

b) Abrasion, attrition:

Abrasion of the cliff face leads to basal notching of the cliff. Basal notching is a phenomenon that is extremely common within the study area (Figure 2.1). Notches as high as 3 meters and as deep as 4 meters were observed. Pronounced notching usually results from refracted wave energy as discussed in 3.3.2.a. Basal notching may directly contribute to cliff failure through undercutting of the cliff's support and collapse of the upper surface zone. This notching most probably acts as a contributor to cliff failure in promoting rock fatigue in the upper surface zone through, (1) progressive deepening of the notch and (2) as a potential air pocket for hydraulicing effects of wave uprush (section C).

Abrasion of shore platforms also has been noted. This is usually accomplished through concentration of abrading materials in a small area (Figure 3.15).

Most abrasion tools take the form of sand and pebbles. In the Bay of Fundy, pulpwood and other forms of driftwood are also quite common, probably acting as abrading agents. As sand and pebbles abrade exposed surfaces they, in turn,

Figure 3.15 - Abrasion pocket development on shore platform. Note presence of abrading tools in left foreground.

undergo size reduction through the process of attrition. This rounding of the pebbles is observed in most places along the coast. Figure 3.16 shows some well rounded, well sorted material. Large rocks and particles may also undergo attrition but they are most probably prepared for attrition through abrasion processes.

c) Hydraulicing:

Goldthwait (1924) suggests one of the chief erosional processes at work on Nova Scotia cliffs to be compression and subsequent expansion of air by waves, as they work against the cliff and then withdraw. Notches may be initiated through this process as well as through abrasive processes. Hydraulicing is suggested by King (1972) as probably the most effective form of wave attack on cliffs. Direct force of the waves may enclose a pocket of air which acts to concentrate shock pressures on the notch or gap in which it is concentrated. This hydraulic pressure acts in a positive feedback manner such that the larger the gap in which the air is trapped, the larger is the subsequent shock.

d) Swash - backwash, longshore transport:

Swash and backwash processes are particularly important during rising and falling stages of lower tidal levels, much less so at higher tidal levels when the beach or platform is completely covered. There are two significant contributions of swash - backwash. The first is to aid the abrasion and attrition of the foreshore, backshore system. Of even greater importance is the role of swash - backwash

Figure 3.16 - Beach materials typical of study area are well sorted and rounded.

in longshore sediment transport.

Rates and effectiveness of longshore sediment transport have a direct bearing on beach formation, removal of upbeach material and subsequently, erosion. Beachs can only be formed when sediment supply exceeds sediment removal. Removal of material relates to the efficiency of transport by the waves. If they are already sediment laden, then they have little capacity to remove more material. Sediment starvation occurs when longshore transport is interrupted by a sediment trap such as a ledge or wharf. The downbeach side of the sediment trap is subject to a greater potential sediment movement due to the increased efficiency of the waves. This most often results in increased sediment or debris removal and subsequent erosion.

Net longshore sediment transport along the south coast, Bay of Fundy, is from the west because of the predominant westerly fetch component. Sources of sediment for longshore transport include cliffs and the remnants from cliff failure, till exposures and slumped till at drainage confluences, and debris from glacial deposits such as outwash at McNeily and Turner Brook together with minor fluvial contributions. The relatively regular outline of the coastal zone of the study area probably indicates a very efficient overall transport regime. Sediment is removed as fast as it is made available. Two possible destinations exist for this sediment. The Bay of Fundy itself, due to the proximity of a steep offshore gradient to the shore line, acts as a sediment sink. Material which remains in transport for

extended periods of time may be caught in the Scot's Bay area, the huge northerly curved area of Cape Split to the east of the study area. This is the most significant sediment trap in the Bay of Fundy. Efficient removal indicates potential for high rates of erosion, since little protective material is left to front the backshore.

Examination of the study area on a more detailed basis, than above, reveals a system of sediment traps interwoven with areas of active longshore transport. Straight segments of unprotected cliffs are quite common. These are characterized by exposed shore platforms as at Kirk Brook (Figure 3.17). Sediment traps on a local scale usually take the form of wharfs or ledges. The ledge feature west of Chipman Brook (Figure 3.18) is an example of upbeach accretion and downbeach starvation. A more temporary form of sediment trap is that formed as a result of cliff failure (Figure 3.19). The debris forms a barrier to longshore transport and until it is removed through processes of abrasion and attrition, plays a significant role in local shorezone dynamics. The relationship of longshore transport and sediment starvation has been demonstrated. The factor of fall debris acting as a sediment trap, leading to downbeach starvation, is an important consideration which will be returned to in Chapters 4 and 5.

3.3.3 Sea Ice

a) Effect on abrasional processes:

Sea ice may act directly as an abrading agent, in the case of drift ice, or it may act to retard the abrasional

Figure 3.17 - Shore platform development at Kirk Brook. Note greater cliff erosion in foreground related to the exposed shore platform of that area. The background area displays less evidence of erosion, most probably due to the protective boulders fronting those cliffs.

Figure 3.18 - Storm ledge at Chipman Brook causing upbeach accretion relative to direction of dominant longshore drift.

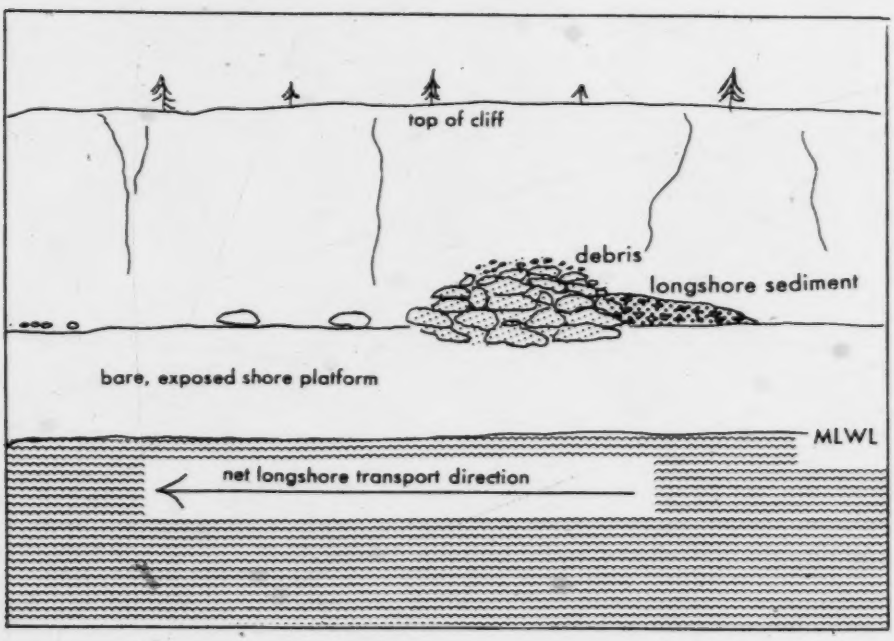


Figure 3.19 - Debris accumulation acting as as sediment trap.

processes of waves, either by dampening of wave height or forming a protective beach cover through ice foot formation or ice crust cover (Zenkovich, 1967).

Owens (1977) states that the Bay of Fundy is never frozen over and in some years very little ice of any kind exists in the bay. He also reports some ice foot development, but due to repeated freezing and thawing, it too is of little importance in the above context. (However, as ice foot formation includes covering of the cliff face, this may be a significant factor in promoting increased cleft water pressure as discussed in section 3.2.2.b). The sea ice which does form is generally in the form of drift ice and small individual floes, which may be of minor importance as abrading tools. Zenkovich (1967) suggests that such abrading tools have the same effect as driftwood. However, he says driftwood is far more important in the USSR. The large amount of driftwood found along the Bay of Fundy suggests that his observation may also be valid for this area.

b) As a transport mechanism:

Various studies (Hind, 1875; Atlantic Fundy Tidal Power Programming Board, 1969; and Knight and Dalrymple, 1976) on the upper regions of the Bay of Fundy, most particularly the Minas Basin, indicate the importance of sea ice in transport and deposition of sediments. Hind (1875) examined ice floes and determined that 85 million kilograms of mud were transported annually in this manner.

In the open part of the bay this factor is probably

far less significant. Ice rafting may account for a small amount of transport of larger sized sediment. Knight and Dalrymple (1976) suggest that coarse sediments, up to boulder size, may be transported in this manner. As the predominant fetch is from the north, ice may be able to incorporate some of the boulders from fall debris on the south coast, thus removing it.

CHAPTER IV

CONTEMPORARY PRODUCTS

4.1 Introduction

The concepts of environmental controls and process factors have been introduced in Chapters 2 and 3. Their relative importance in the Bay of Fundy system, together with the degree of interdependence they exhibit, have been discussed. Most contemporary products are produced by these factors and those that are not involve feedback links, from these contemporary products, which will be discussed in Chapter 5. Contemporary products involve shorezone form at any one point in time. Thus factors which constitute the shorezone, such as cove form, cliff form, platform development, etc., are contemporary products.

Shorezone dynamics along the south coast, Bay of Fundy, mainly involve erosional processes. Erosional processes are responsible for cove form, cliff retreat, and platform gradient. Within the study area approximately 165 rock debris accumulations, indicative of erosional processes, were studied. It is estimated that these debris accumulations amount to a total mass of 1.4×10^6 tonnes produced over a period of fifteen years (the basis for this estimate will be discussed in section 4.3.2). This exemplifies the dynamic nature of the coastal zone. As cliffs retreat, debris accumulates in the intertidal zone and the total shorezone morphology constantly changes. Within this hierarchy of processes and responses the shorezone morphology is

chiefly characterized by cove form. The next order examined is the backshore of the coastal zone, cliffs, till exposures or low ledges. The third order comprises the foreshore and intertidal zone of beach development, platform erosional forms and platform partial accretion forms.

4.2 Cove Form

a) Classification:

The comparatively regular, unindented nature of the coastline from Parker's Cove to Baxter's Harbour does not appear to contain any significant coves in the sense of the traditional definition of such features. Monkhouse (1970) defines a cove as "a small rounded bay, usually with a narrow entrance". The exceptions to the generally unindented coastline in this area do deserve examination. Thus a more general definition of cove is proposed here as, "any area in which protection from the predominant fetch, is offered in the form of a projecting part of the coastline". In terms of this definition several areas including Parker's Cove, Hampton, St. Croix Cove, Port Lorne (harbour), Port Lorne Cove, Margaretville, Morden, Harbourville, The Cove and Baxter's Harbour may be classified as coves.

b) Origin:

In most cases the key to the origin of these coves is the existence of a projection along the coastline. This projection leads to wave refraction which accelerates subaerial processes resulting in indentation taking place. Significant cove development signifies a pronounced projection of the point and leads also to wave diffraction, plus

differential orientation of the cliff face to marine and sub-aerial processes.

Points originate as a result of two factors. A point may be part of a synclinal trough line, as are Margaretville Point and Cranberry Point (west of The Cove). Coves may also result at the confluence of streams and the coastal zone. It has been noted how drainage within the study area is structurally guided and trends to the west wall of the joints within which they are resident. The east wall is generally filled with till overlying sharply dipping bedrock. This provides conditions for enhanced coastal erosion and cove formation. The west wall remains relatively intact while the east side of the joint becomes more recessed due to its orientation with respect to the direction of effective fetch. Examples of this include Parker's Cove and Baxter's Harbour.

Two notable cove exceptions, which are not primarily dependent on the existence of a point for development, are Hampton and St. Croix Coves. Both of these lie on anticlinal crest lines and owe their origin primarily to the fact that they have a greater range of exposure to marine and subaerial processes then do adjacent areas.

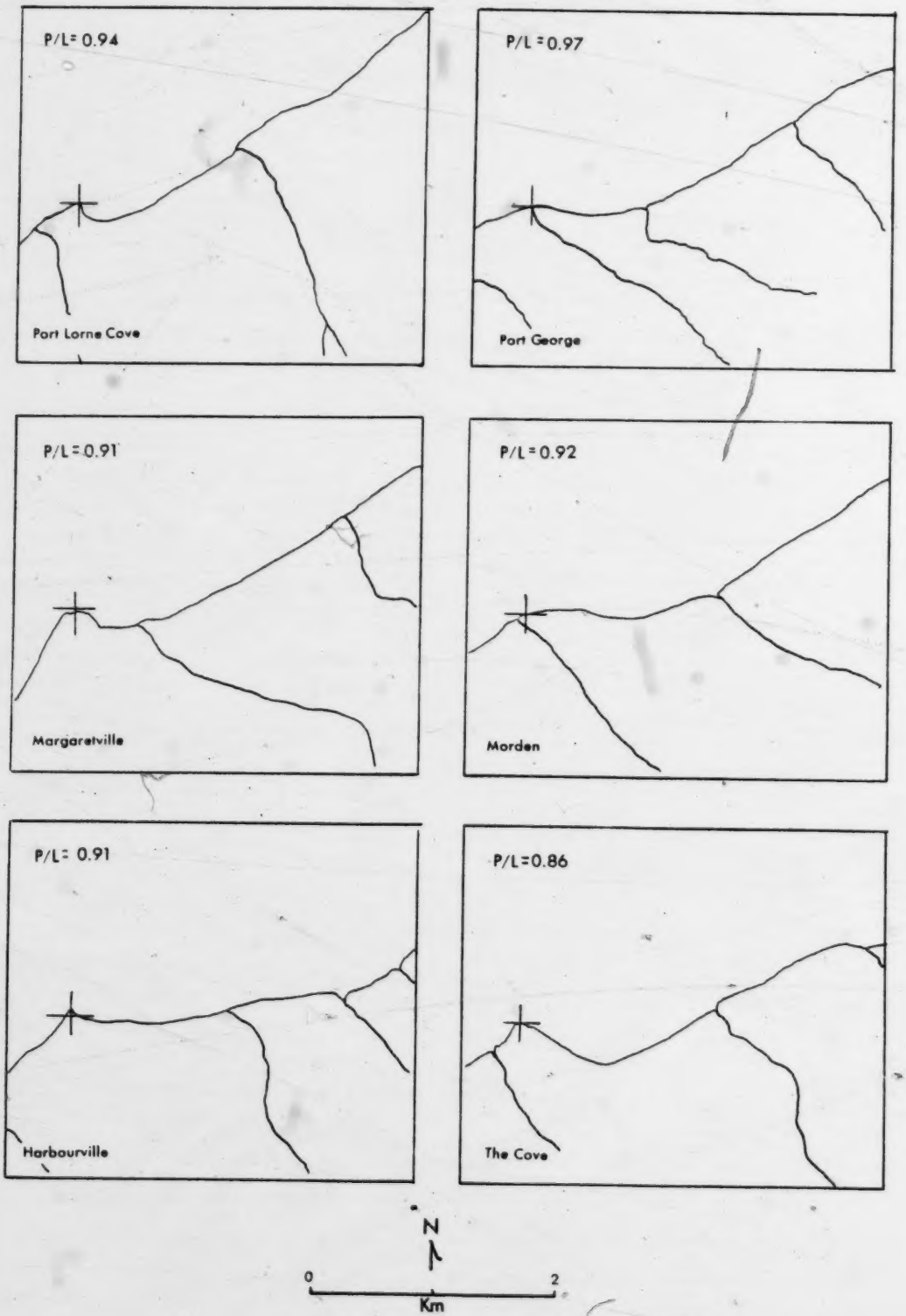
c) Morphometry:

Coves formed in the lee of a synclinal trough line in the study area, tend to be gentle in outline with a maximum indentation of 0.5 kilometers and a mean length of 2.2 kilometers. A comparison of the outlines of Port Lorne Cove, Port George Cove, Margaretville, Morden, Harbourville and

The Cove reveal a trend of increasing indentation in a westerly direction (Figure 4.1). A P/L ratio, where P is the planimetric length of the cove and L is the equivalent longshore distance, was used as a measure of indentation. A greater L value indicates a lower P/L ratio and thus increased indentation. This is reflected in the P/L values for Port Lorne Cove (westerly) and The Cove (most easterly) being respectively 0.94 and 0.86. Intervening values are given on Figure 4.1a and are relatively consistent with this trend.

Cove form is largely determined by joint - orientation, as discussed in Chapter 2. Primary joints are oriented in two basic directions leading to a series of offset blocks along the backshore of the Cove. Examples of these offset features are particularly pronounced at Margaretville and The Cove.

Coves formed at drainage confluences are generally much less extensive in area than are the synclinal coves. Comparisons of Parker's Cove with Margaretville, or Port Lorne (harbour) with The Cove, readily demonstrate this. The dimensions of Parker's Cove are 0.2 kilometers deep with a planimetric length of 0,75 kilometers. Baxter's Harbour and Port Lorne (harbour) are both approximately 0.15 kilometers deep and 0.20 kilometers in length. These coves, although smaller, are of greater importance from an economic standpoint than are the synclinal coves. This is due to their comparatively pronounced indentation which affords better protection for wharves and small craft.



Degree of indentation of six coves

Figure 4.1 a

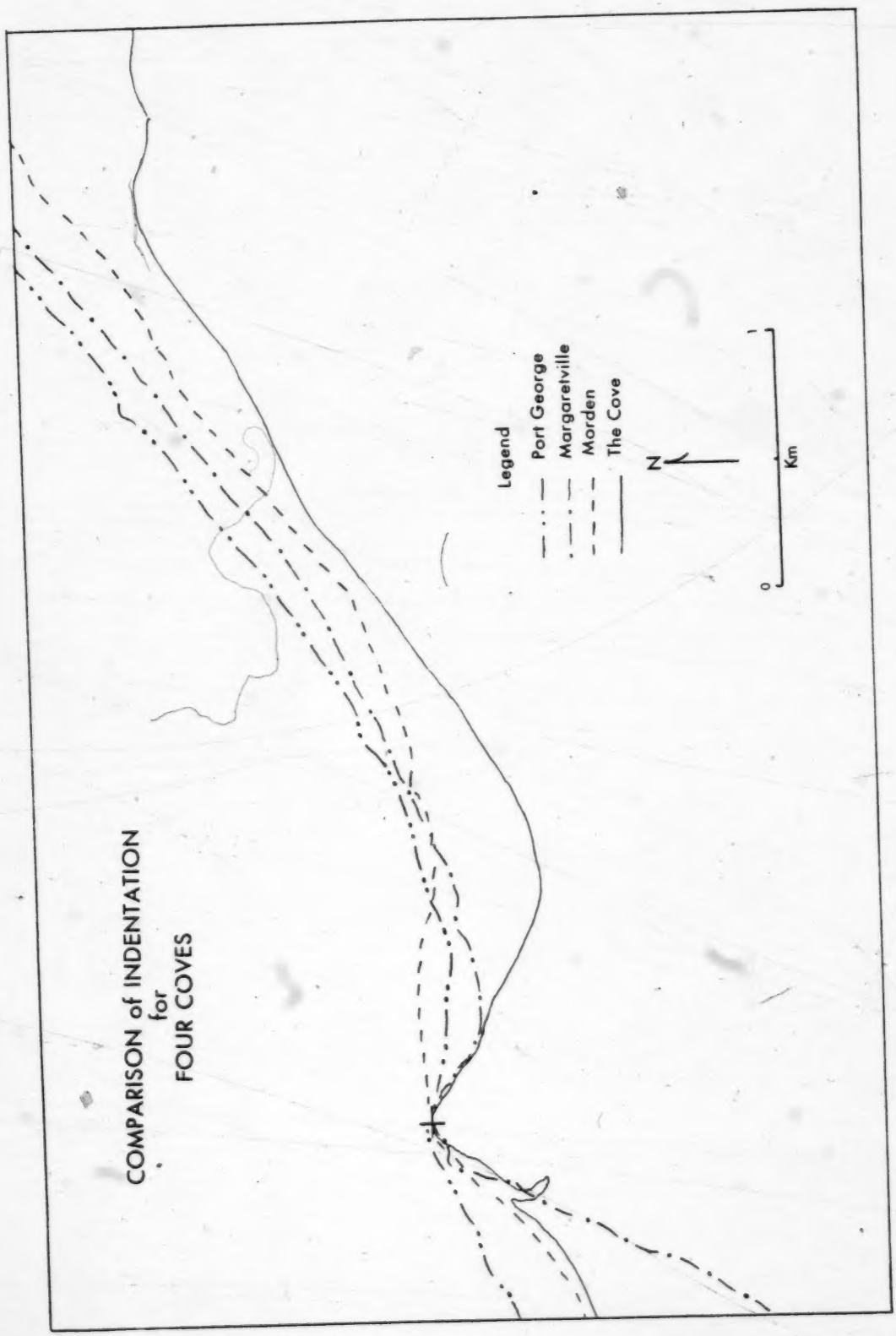

COMPARISON of INDENTATION
for
FOUR COVES
Legend
Port George
Margaretville
Marden
The Cove
N
0
Km

Figure 4.1 b

Coves are more numerous along the predominantly cliffed sections of the study area, than in the non-cliffed resistant sections which are found from Hampton, westward. This is consistent with the higher amounts of erosion noted east of Hampton, as discussed later in this chapter.

Historical evidence in the form of raised beaches at Hall's Harbour and Turner Brook, as identified by Hickox (1958), indicate the maximum degree of indentation achieved by previous higher, sea levels. Past cove forms seem to have been consistent with contemporary cove forms, displaying no apparent anomalies in terms of what might be expected for future development.

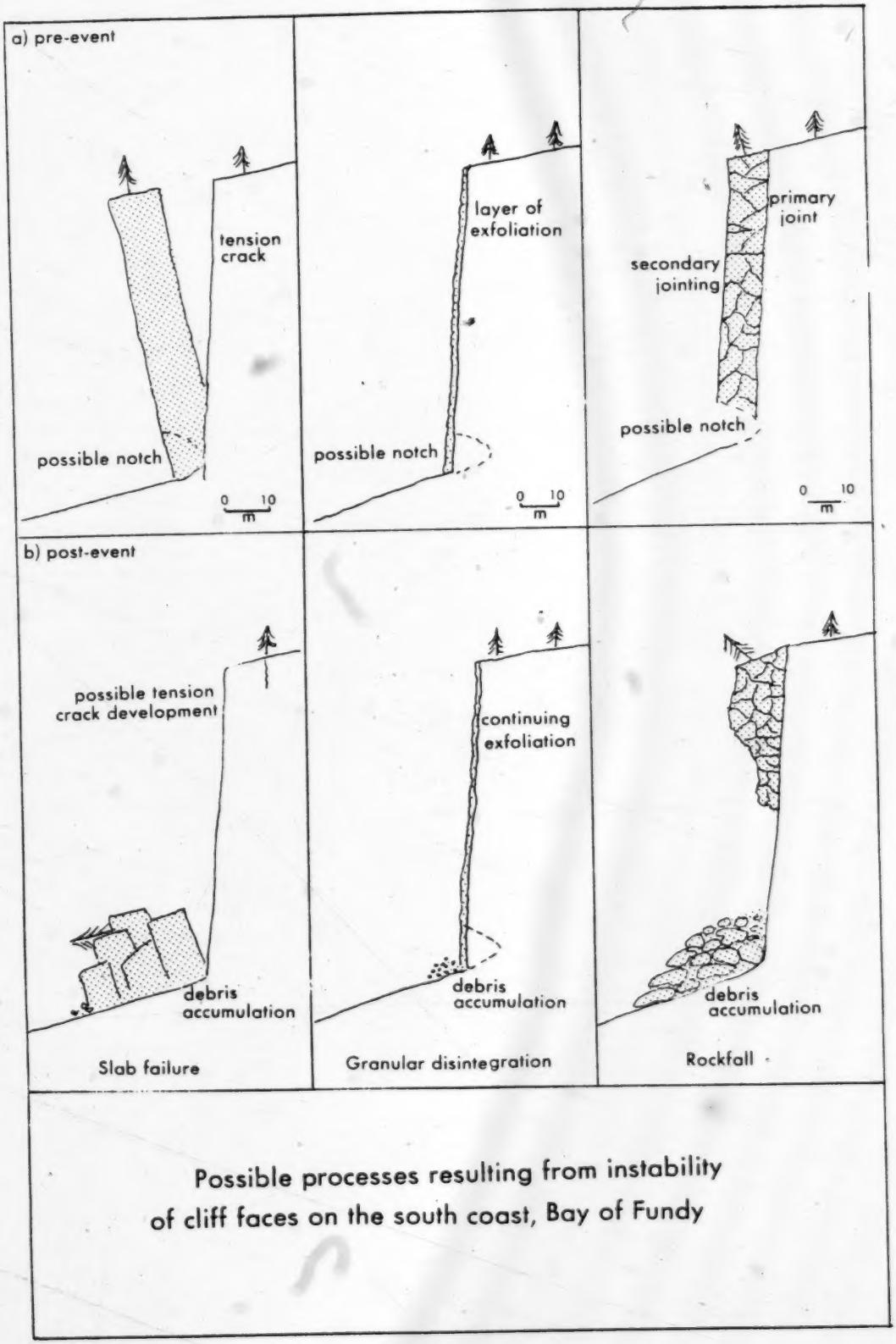
4.3 Backshore Form

4.3.1 Highly Resistant Cliffed Coasts (Type Ia)

As the coastline in non-cliffed areas appears relatively uniform, while a comparatively high degree of indentation exists along cliffed sections within the study area, the dynamics affecting cliff form are of great significance. Without changes in cliff form it is obvious that there would be no significant change in overall coastal form. This is due to the fact that in terms of longshore sediment budget, the south coast is a net eroding coast as opposed to a net accretionary coast.

a) Forms of retreat:

Cliff retreat within the study area takes three basic forms. These forms are (1) slab failure, or toppling, (2) rock falls and (3) granular disintegration (Figure 4.2). Approximately one hundred sixty-five debris accumulations were



Possible processes resulting from instability of cliff faces on the south coast, Bay of Fundy

Figure 4.2

Figure 4.3 a - Impending slab-failure west of Morden. As this is an area well-protected by debris accumulations, the cliff failure in this case is most probably due solely to sub-aerial factors.

Figure 4.3 b - Small rockfall at The Cove. The scar on the cliff face reveals the source of the fall debris. This rockfall took place in late December, 1977 (M. Mosher - pers. comm., 1978).

examined during the summer of 1978. Of these, twenty-three could be identified as products of slab failure. Thirty-one were classified as products of rockfalls. The remainder could not be assigned to any particular category due to the high degree of shattering characterising the fall debris. The products of granular disintegration were not recorded because of the spatially diffuse nature of this process.

In terms of volume removal at a particular time, slab failure is the most significant process. A single block resulting from slab failure at The Cove was found to be 55 cubic meters and estimated to have a mass of 130 tonnes (1 cubic meter of basalt is equivalent to 2.4 tonnes). The debris which included this block had an estimated total mass of 99×10^3 tonnes. This, however, is an abnormally high mass. A more realistic value for intact debris resulting from slab failure is in the area of 12×10^3 tonnes. This may be compared to rockfalls which appeared to have a mean mass of 500 - 1000 tonnes per individual debris accumulation. Granular disintegration appears to be on a far smaller scale than either of the other two processes. However, it is very difficult to accurately assess specific volumes of granular disintegration in terms of debris accumulations.

b) Rates of retreat:

Debris accumulations were used as a crude indicator of rate of cliff retreat in place of sequential aerial photograph imagery. Aerial photographs for 1931, 1945, 1963,

1967, 1973, 1975 and 1977 were examined. A high degree of tilt and lack of registration points made it impossible to identify, in detail, rates of retreat by using a zoom transfer stereoscope. It was possible only to determine that horizontal rates of retreat (in terms of the cliff face) for the period 1931 to 1973 were less than 2 meters.

Using the measured volumes of 35 of the total 165 debris sites examined within the study area, a mean volume for debris accumulations was calculated. This was applied to the following formula:

$$R_t = \frac{\bar{X}D \times N}{L \times \bar{X}Ch} \qquad (1)$$

where R_t is the rate of retreat for a specified time t, $\bar{X}D$ is the above mean (in this case 3608.3 m^3), N the total amount of debris accumulations (165), L is the longshore length of cliffed section within the study area (from St. Croix Cove to Long Beach = 76 km) and $\bar{X}Ch$ is the mean cliff height for the specified section (29.14 m). This is then applied to a value of t = 15 years, the maximum residency period for debris accumulations within the study area (determined from air photos). The R value obtained is 27 cm for 15 years. This is considered a conservative value as not all the 76 km is cliffed and mean cliff height was calculated from measurements at specific localities where cliff heights may be at a maximum (i.e. east limbs of coves). As, the existing debris accumulations are being constantly reworked by marine action, measurements of debris seldom produce a value equivalent to the total volume

removed from the cliff face. These measurements also fail to consider the role of granular disintegration. The aerial photograph interpretation indicated that the maximum residency time for a debris accumulation was fifteen years. However, many disappear faster, indicating that L from equation (1) might be somewhat less. These considerations all tend to suggest that an appropriate R value might be slightly higher than 27 cm. However, this value is probably of the right order of magnitude.

c) Resultant morphometry:

The process of retreat results in specific effects on cliff form. Slab failure is observed to lead to almost 90° slopes with headlands being removed, in turn leading to regularity of cliff outline (Figure 4.3a). Rockfalls may also produce a near vertical cliff through the process of overhang collapse in places where notching is common. Often rockfalls act to decrease the slope of the cliff face to a value of 70 - 80° in places where only the top section of the cliff undergoes significant retreat (Figure 4.3b). Granular distintegration results in fairly even retreat over the cliff face. However, it may act as a differential erosion agent, leading to increased cove indentation in some cases, and enlarged joints in others.

4.3.2 Highly Resistant Non-cliffed Coasts (Type I-B)

As has been discussed previously, this type of coast is characterized by a relative absence of erosional processes as compared to other coastal types within the study area. This accounts for the relative uniformity in coastal

outline from Parker's Cove to Hampton which is all type I-B coast. Erosional processes operating on this section of coast must act to produce parallel retreat. The only significant exception to this is Parker's Cove, discussed earlier.

4.3.3 Poorly Resistant Shorelines (Type II)

a) Forms of retreat:

Turner Brook, Meekin Brook, McNeily Brook and Hampton contain the largest sections classified as poorly resistant shorelines. Processes of retreat may be placed in two categories. Major bank failure events take the form of slumps. Continual removal of material without apparent slumping is termed bank retreat. Bank retreat is the most common as it is controlled primarily by the efficiency of longshore sediment transport. As a net deficit exists in terms of longshore sediments, material from easily erodible sources is constantly being drawn upon. This results in essentially parallel retreat along an exposure with little slumping. Slumping occurs when the rate of sediment supply exceeds rate of demand in terms of longshore transport. Thus the one major slump observed within the study area was at the western end of the 2.5 kilometer outwash exposure at McNeily Brook (Figure 4.4). There is little immediate downbeach demand for sediment thus, when bank failure occurs, the remnants exist in the form of slump debris.

b) Rates of retreat:

Rates of bank failure for type II coasts within the study area are potentially much greater than those for

Figure 4.4 - Slump in glacial outwash material at McNeily Brook. This was the only major slump observed in the study area. The staff located in lower, right foreground is 2 m high.

surrounding areas. During February - March, 1978, bank retreat was observed to be 3 meters, both at Hampton (Floyd Cropley, pers. comm.) and at Harbourville (Ken Perry, pers. comm.). In the summer of 1978 measurements were made from the northwest corner of the house lying on the eastern side of the Port Lorne church to the edge of the bank which is eroding back toward it. These were compared with values measured from 1955 and 1978 air photography and the results are presented in Table 4-1. Over 8.0 meters of bank recession have been noted in the last 13 years with 3 meters in the last 3 years. This is in accordance with the observations made at Hampton and Harbourville and tends to confirm the episodic nature of erosion along the coast, a factor which will be returned to in Chapter 5.

c) Resultant:

Erosion or retreat of poorly resistant shorelines has led most commonly to the formation of coves. Hampton is the most pronounced example of this phenomenon. Other areas include Port Lorne (harbour), Meekin Brook and Square Cove. All of these are areas where the till - filled east side of the joints are eroded leading to small coves. The banks are usually steep sloped - McNeily Brook banks lie at an angle of approximately 60^{o}.

4.4 The Foreshore and Intertidal Zone

4.4.1 Platform - Ledge Erosional Forms

a) Classification:

Within the intertidal zone of the south coast, Bay of Fundy, several erosional forms may be identified. The

TABLE 4-1

DISTANCE OF A HOUSE AT PORT LORNE FROM THE EDGE OF THE BANK

YEAR	DISTANCE
1955	13.2 m
1975	8.11 m
1978	5.0 m

three most common have been classified using an adaptation of Trenhaile's (1974) classification scheme. They are; contemporary shore platforms, storm ledges and raised storm ledges. An additional class is used in this study, potholed platforms (a sub-category of contemporary shore platforms).

Contemporary shore platforms, in Trenhaile's (1974) terms, are essentially rectilinear surfaces with gentle seaward dips (3^{o} - 6^{o}) which reflect local environmental conditions. Potholed platforms occur where basaltic columnar structures are conspicuous and consist of abrasion pockets scoured out by available tools. Contemporary shore platforms, both exposed and vegetated, are the single most important intertidal feature within the study area and account for over 50% of the coastal zone. Storm ledges have sub-horizontal upper surfaces. However, their primary control is lithological rather than environmental. They show little if any dip and usually terminate in a low tide cliff. These ledges most probably have developed as a result of cliff retreat along flow contacts which occur at approximately mean sea level. This would account for the low tide cliff and the intertidal nature of this form. Storm ledges are products of erosion and seem subject to only negligible subsequent erosion in comparison with the backshore. However, a number of authors have proposed that similar rates of retreat hold for low and high tide cliffs (Bartrum, 1926; Cotton, 1963; among others) with the platform - ledge complex remaining in a dynamic equilibrium. It is beyond

the scope of this study to pursue this theory, although low-tide cliffs should be considered as possible erosional forms.

Raised storm ledge surfaces usually stand 1 to 4 meters above adjacent surfaces. They are generally narrow and extend for only limited distances in the intertidal zone. Although lying within the intertidal zone, they are often emergent at high tide. Storm ledges are also most likely a product of lithology and correspond with the flow-contact, marine planation level. In many cases these ledges occur where only one flow is exposed, as has been discussed in the case of synclinal trough lines. The significance of erosion on these forms has also been discussed in the previous chapter.

b) Morphometry:

Trenhaile (1974a, 1974b, 1978) has shown that a strong correlation exists between the gradient of shore platforms and tidal range for specific areas. He suggests that an increase in tidal range leads to the distribution of wave energy over a greater area and hence produces a steeper platform. Testing this theory for the Bay of Fundy situation consisted of measuring slopes of the platforms. This was done by means of reciprocal levelling using a Wild automatic level and 25 foot (7.9 meter) rod. The specific survey locations are shown on Figure 5.5. Specific sites examined from the west to the east of the study area seemed to confirm that such observations are also valid for the Bay of Fundy. Table 4-2 lists regression coefficients (slope of the platform) together with residual squared

TABLE 4-2

STATISTICS OBTAINED FROM SURVEY DATA

	Profile Location	a	b	R-Squared
1	Parker's Cove	4.538	-.066858	.98212
	Margaretville			
2	west wharf	5.760	-.112272	.98752
3	east wharf	3.222	-.076374	.98947
4	cove	0.967	-.072927	.91425
5	cove	0.354	-.058496	.93186
6	cove	1.146	-.077666	.96815
	Morden			
7	between ledge and weir	3.521	-.111779	.98582
8	west of ledge	7.462	-.116274	.94910
9	through ledge	-1.573	+.024414	.56079
10	east ledge	2.900	-.076432	.99620
11	cove	3.094	-.059468	.95734
12	cove	1.825	-.077046	.94694
	Harbourville			
13	west wharf	6.060	-.110088	.97545
14	east wharf	5.732	-.064261	.97224
	Hall's Harbour			
15	west wharf	8.195	-.095310	.98575
16	parallel to berm	4.597	-.096831	.65701
17	normal to 15	8.177	-.070804	.96184
18	east wharf to Cranberry Point	7.427	-.049164	.96000
19	normal to 18	6.556	-.079826	.96534
20	east wharf	4.824	-.025892	.84812
21	end of weir road	2.602	-.064190	.91922
22	cove	0.718	-.110196	.98672
23	cove	2.305	-.095497	.99517
24	cove	4.114	-.110365	.98857
25	cove	1.653	-.090880	.99186

(goodness of fit) values. Figure 4.5 is a graph comparing slope with longshore distance. It seems to show a trend confirming Trenhaile's theory. The limited number of data points collected must place restrictions on these observations. In order to test the significance of this data, a student t test was applied to the two clusters of data points separated by the natural break as shown in Figure 4.5 (statistical procedures and results are outlined in Appendix III). The results of this application tended to show that the observed increase in platform gradients between Parker's Cove, Margaretville and Morden profiles, as compared with those of The Cove, has not occurred by chance. A visual comparison of the surveyed profiles is given in Figure 4.6.

4.4.2 Platform Partial Accretionary Forms

a) Classification:

Platform partial accretionary forms are the most temporary morphological features within the study area. Their residency possibly may extend from a minimum of hours to a maximum of fifty years depending on what form they take and the degree of exposure experienced by each.

The most spectacular partial accretion forms are the debris accumulations resulting from slab failures or rockfalls. These features usually enjoy the longest residence time with some of the larger sized boulders being estimated to last as long as fifty years before being reduced and removed through a combination of abrasion and longshore

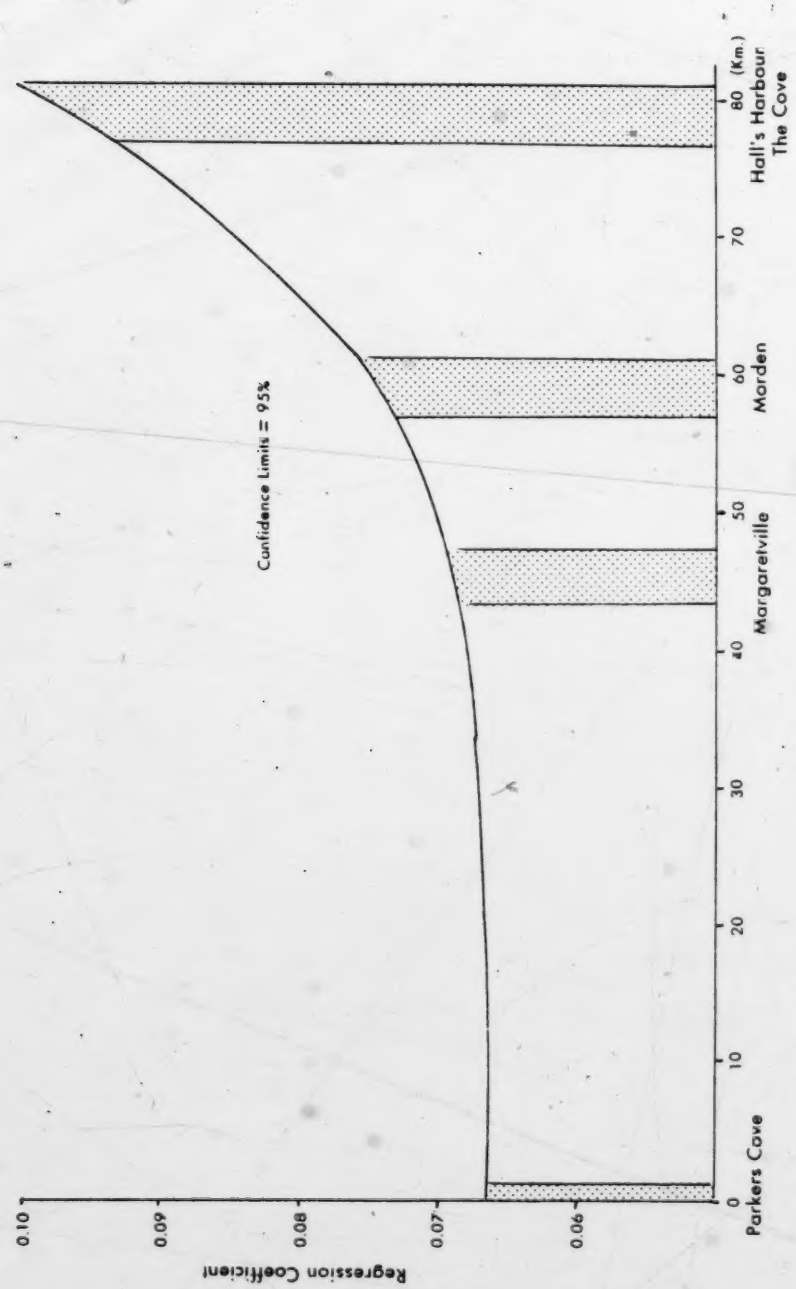


Figure 4.5 - Comparison of shore platform gradient, as represented by regression coefficients, with longshore distance.

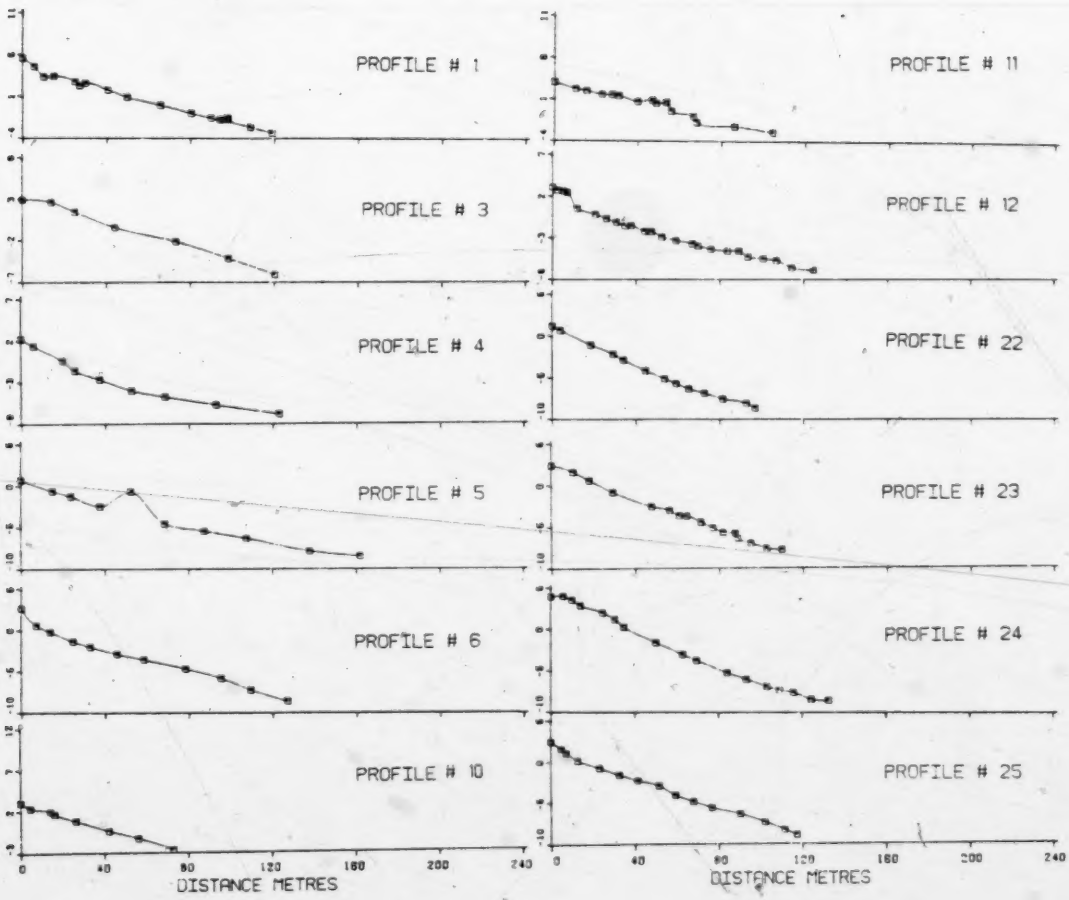


Figure 4.6 - Surveyed profiles normal to the cliff face for selected locations in the study area.

agents. Boulder fields are also quite prominent and most likely exist as remnants from debris accumulations. However, due to their age and possible distance that they have been transported (longshore and/or shore normal) they are classified separately from debris accumulations. Abraded fragments from debris accumulations and boulder fields may take the form of isolated patches of cobbles. These cobbles may act as abrading tools while undergoing attrition themselves. Cobbles probably have a very short residency time due to their transportable sizes. Silts and sands are also found in the intertidal zone. Sands are usually in transit from another source. In at least one case (Figure 4.7), sand and silt are the products of fluvial delivery.

b) Morphometry, magnitude, location and frequency:

Debris accumulations are generally highly localized or confined with an angle of repose ranging from 8^{o} to 34^{o}. The angle of repose and degree of confinement generally decrease with age. Figure 4.8 shows the frequency of these accumulations with respect to geographic location. A general increase in frequency is observed upbay (in an easterly direction). Figure 4.9 compares the magnitude in terms of volume for specific debris accumulations near Margaretville and The Cove. A significant increase in magnitude upbay may be inferred from these maps. Thus, not only are there more debris accumulations in an easterly direction, these accumulations are also much greater in terms of volume.

Boulder fields are much greater in areal extent than

Figure 4.7 - Sand ripples at confluence of Bear Brook and the Bay of Fundy. This is one of the few areas within the study area observed to be affected by fluvial action.

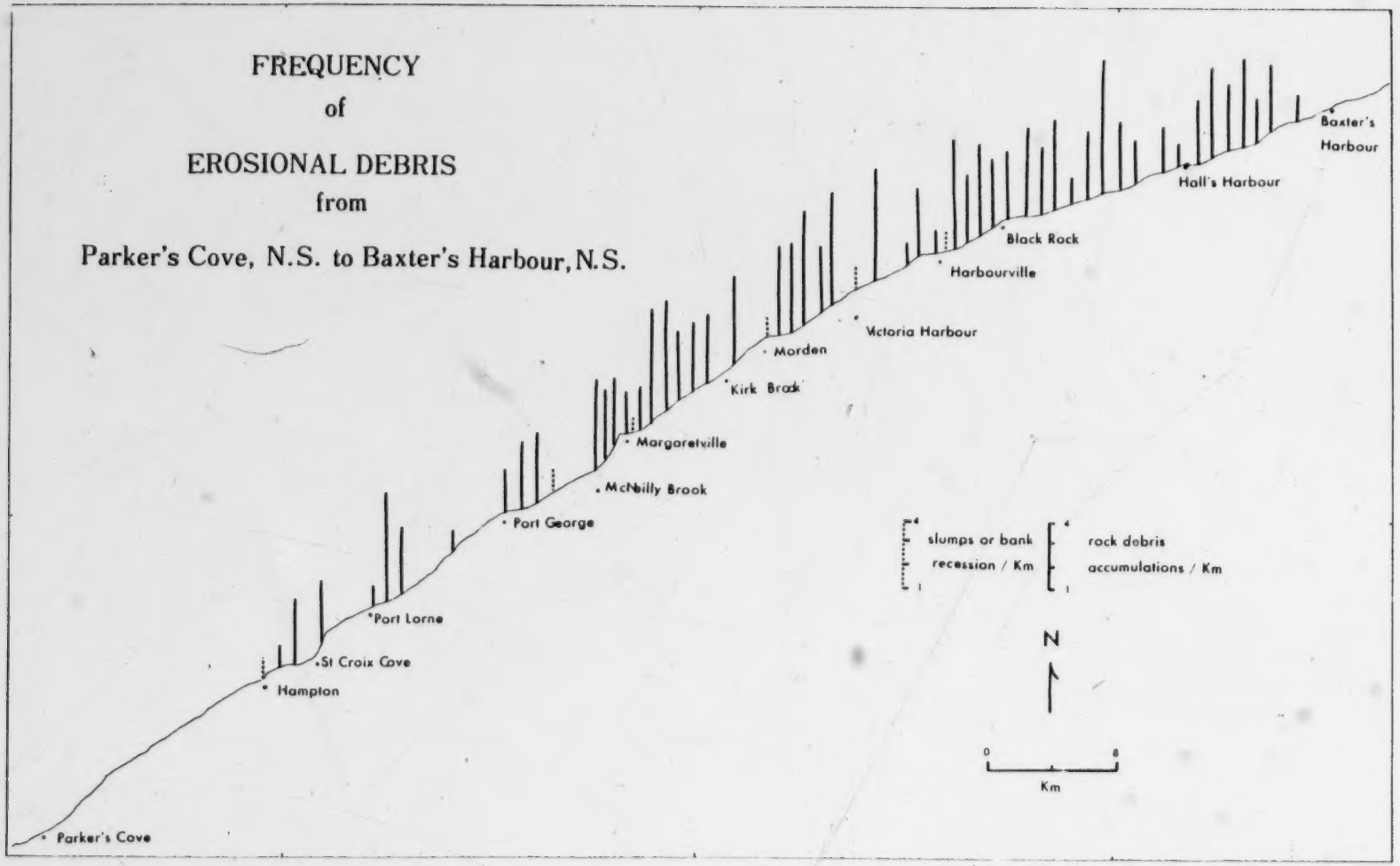

FREQUENCY
of
EROSIONAL DEBRIS
from
Parker's Cove, N.S. to Baxter's Harbour, N.S.
Parker's Cove
Hampton
St Croix Cove
Port Lorne
Port George
McNeilly Brook
Margaretville
Kirk Brook
Morden
Victoria Harbour
Harbourville
Black Rock
Hall's Harbour
Baxter's Harbour
slumps or bank recession / Km
rock debris accumulations / Km
N
0
8
Km

Figure 4.8

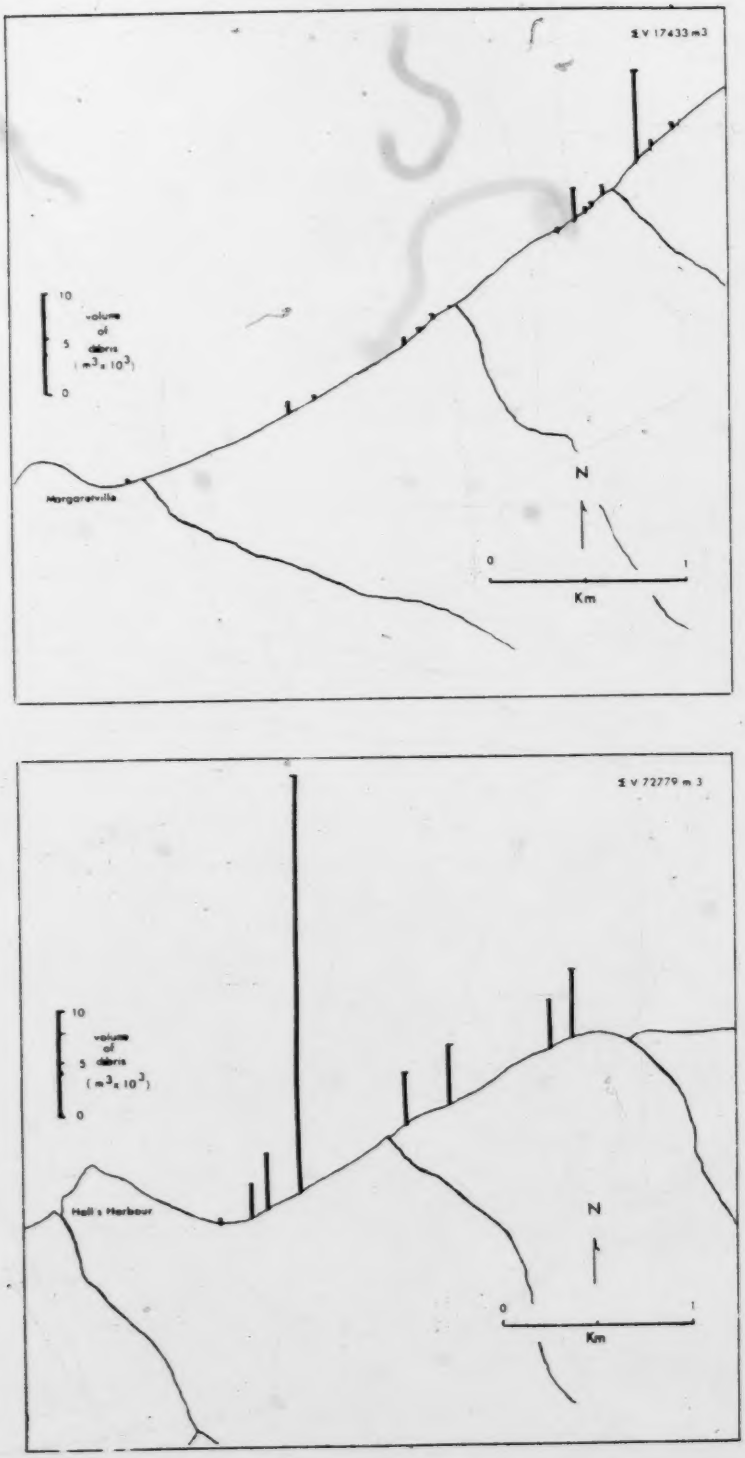


Figure 4.9 - Comparison of debris accumulations at Margaretville and The Cove.

debris accumulations. They may leave patches of platform exposed. Cobbles and sand may only partially cover a platform. In such cases the finer sediments are likely to be transported very often and assume no consistent form with respect to the intertidal or foreshore zone. Silt and sand may also form in ripples as is the case at Bear Brook (Figure 4.7) and The Cove.

4.4.3 Beach Development

a) Classification according to types of sediment traps:

In this study, beach development is defined as taking place when sediment accumulates in the form of a berm or series of berms. In order for this to occur, conditions favouring sediment arrest from longshore transport must exist. The restricted beach development along the south coast, Bay of Fundy, may be related to two main reasons. First, is the availability of material for transport and, second, is the lack of sediment traps along the relatively uniform coast.

Sediment traps, within the study area, take several forms. Some coves provide sufficient protection for significant sediment accretion. Hampton is an example of this. More often accretion takes place on the west side of the points adjacent to coves. This is the case west of Margaretville Light. Deposition may take place on a seasonal basis at the confluence of joint-controlled drainage as at Square Cove. Two of the most effective forms of sediment trap within the area are raised storm ledges and their artificial counterpart, wharves.

b) Morphometry:

Gradients were measured from the backshore to the water's edge and calculated by means of linear regression for the east and west sides of wharves at Margaretville, Harbourville, Hall's Harbour and a significant ledge development east of Morden. They were plotted as shown in Figure 4.10. Gradients were observed to be significantly steeper for shore zones adjacent to the west sides of these features as opposed to those on their east side. The statistical procedure as outlined in Appendix III confirmed the mutual exclusivity of east and west slopes. This served to define direction of longshore transport and determine effectiveness of wharves and ledges as controls or sediment traps. Major implications of this include the probable, eastward, downbeach, sediment starvation of longshore drift and hence the eastward increase of erosion potential.

Beach slopes were measured using a Brunton compass and 2 meter staff. On such a local scale it was considered important to note factors such as aspect, upbeach conditions and degree of exposure in relation to the sample site. Beach slopes seemed to be directly related to aspect. West facing headlands consistently displayed steeper slopes than did east facing sections of headlands. At the same time it must be noted that this difference was only relative to the two values at a specific site. To illustrate this, at Margaretville a value of approximately 6.5^{o} was obtained for the west facing slope while the east facing slope had a mean value of 5.5^{o}. This can be contrasted to

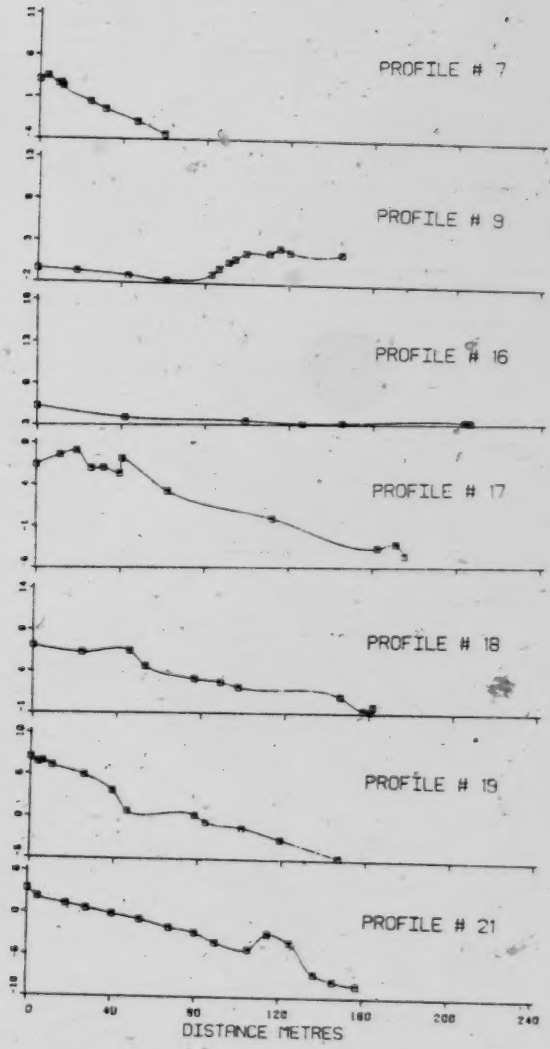


Figure 4.10 - Surveyed profiles adjacent to east and west sides of wharves or storm ledges.

Huntington Point, 38 kilometers to the east, which showed values of 8.5° and 7.5° respectively for west and east facing slopes. This may reflect an increase in slope in conjunction with increasing tidal range in an easterly direction as discussed in section 4.1 above.

Well developed beaches along exposed sections of shoreline, displayed extremely consistent slopes in all parts of the study area. The mean slope of these beaches was 7° with a very small standard deviation (0.29). This may be due to two factors. First, beach development is more pronounced in the eastern part of the study area. This zone reduces the relative longshore distance over which process factors, principally tidal range, may change. Secondly, partially as a result of the first factor, a sample bias exists in favour of the beaches of the eastern end of the study area. Therefore, a rigorous evaluation of the relationship between beach gradient, tidal range and other process factors is not possible.

CHAPTER V

LONG TERM RESULTANTS AND CONCLUSIONS

5.1 Introduction

In Chapter 1 the concept of coastal dynamics is introduced by means of a model. This model suggested that long term resultants in the Bay of Fundy coastal system are a result of complex interaction of environmental controls, process factors and contemporary products. The basis of differentiation between contemporary products and long term resultants pertains to scale. The morphology of contemporary products is only examined at a single point in time. Long term resultants evolve from contemporary products. For example, coastal retreat on the south coast has led to the evolution of a ledge - platform complex backed by steep walled cliffs. At a single point in time the contemporary product may range from exposed shore platforms to large amounts of rock debris in the backshore fronting a well jointed cliff face.

Schumm and Lichty (1965), using river channel morphology as an example, examine the dependence of landforms on the dimensions of time and space. They suggest that depending upon these two dimensions, a landform can be considered as "either a stage in a cycle of erosion or as a system in dynamic equilibrium". Over a very long period of time the system is potentially losing energy and mass in conformity with a cycle of erosion. Over a shorter time period some element of self regulation is introduced,

while at even shorter periods of time the landform may be in a steady state. These last two stages are considered to be the appropriate time perspectives for the long term resultants and contemporary products, respectively, discussed in the present study.

In this study long term resultants may be envisaged to range somewhere between static and dynamic equilibrium states. These resultants must display some features which are characteristic of a dynamic equilibrium in that to a certain extent they govern the rates of their formative processes. However, elements of certain long term changes or trends may also be discerned indicating a cyclic progression or a tendency of the system to approach a state of static equilibrium. Therefore, elements of these two concepts must be considered in order to accurately describe the coastal system.

5.2 Model Development

a) Static Equilibrium:

Davis (1899), Johnson (1919) and others all envisage that the evolution of landscapes constantly moves toward equilibrium. This ideal would be achieved through a balance between erosive forces and resistive forces, where a landscape has undergone a progression from "youth" to "maturity". Such a balance would mean that a state of equilibrium had been achieved. However, such a concept fails to take into consideration global changes such as tectonic movements, glacial events or sea level changes. Thornes and Brunsden (1977) also suggest that a problem of

Davisian cyclic - decay models is that they have a tendency to suggest that time is responsible for landscape change instead of examining the relationship between time, process and form. Davis' (1899) models also have the problem of equifinality in assigning specific causes to specific forms.

b) Dynamic Equilibrium:

Several problems of a decay model or static equilibrium model may be overcome by approaching the problem from a perspective of dynamic equilibrium. Such a model assumes that there is an interdependence throughout the system and concentrates on changes in external controls together with relaxation times (Thornes and Brunsden, 1977). This approach is useful in examining a short term process which is governed by negative feedback. Thus it assumes a rapid buildup to an event and then a dampening due to that event which leads to a subsequent relaxation period. Although such a model is of very limited usefulness on a large time scale, it is useful in this particular study for examining particular erosional events. For example, the model in Figure 5.1 portrays the role played by debris in protecting the cliff face from which it originated. The relaxation time spans the period required for debris removal. However, this also serves to illustrate the basic problem of such a model. It is only capable of describing events on a limited basis and from a narrow perspective. It fails to consider that positive feedback is also generated by cliff failure producing [illegible]s accumulations and

thus leading to increased energy concentration on adjacent non-debris fronted cliffs.

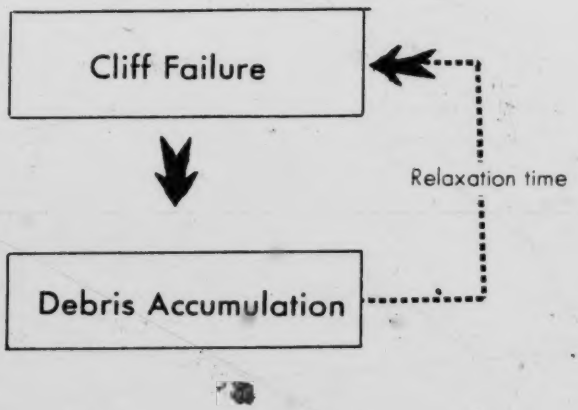


Figure 5.1 - Dynamic equilibrium model.

c) Inductive Evolutionary Model

Therefore, any model of the south coast, Bay of Fundy, system must take into account positive as well as negative feedback links. Such an inductive model is very common in geomorphology. King (1970) suggests that for beach processes very short term changes may be characterised by negative feedback. In medium term changes she suggests there is a lack of feedback and continuous change may take place, while there is a possibility of cyclic changes varying from positive to negative at various points in time and location. This theory most probably has applications for the present study. A modification of

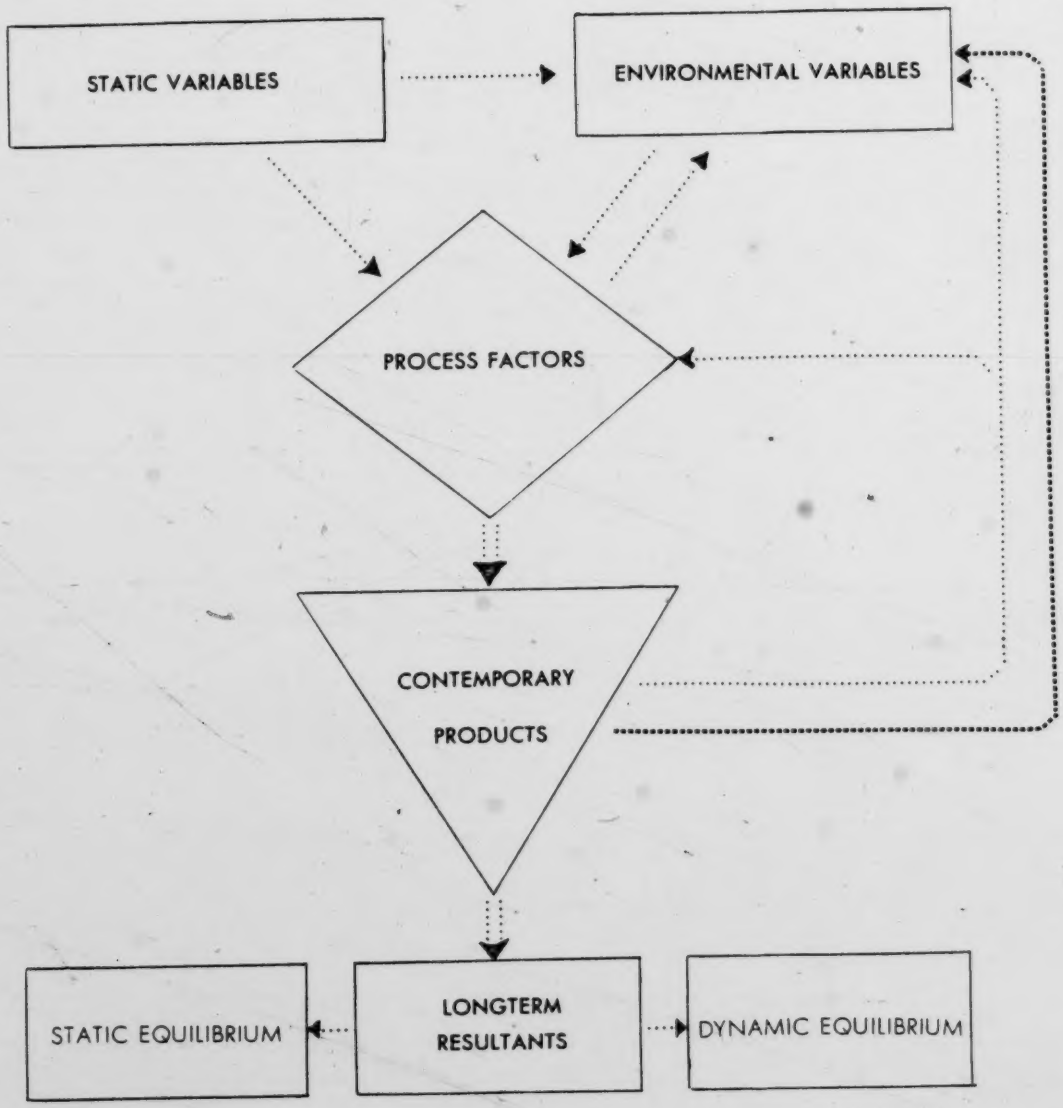


Figure 5.2 - Evolutionary Model.

the model proposed in Chapter 1 demonstrates (Figure 5.2) the interdependency of variables and the possibility of either negative or positive feedback acting at a specific point. It also overcomes the problem of equifinality by showing how similar events may have originated by one or more of several interactions.

The model in Figure 5.2 is a generalization of the specific model in Chapter 1. Insofar as it is a generalization spawned from a specific, it bears similarities to such products as derived by Price (1969) or Brunsden and Jones (1972), from their more complex analyses. Such a general evolutionary model may serve to develop inductive observations, with respect to long term products of the system.

5.3 Input - Output

a) Re-examination of hypothesis:

An examination of the models in Figures 1.3 and 5.2 suggest that they may be divided into two sections, input and output. The most radical simplification of these models could be expressed as in Figure 5.3. Input consists of controls and process factors while output defines contemporary products and long term resultants.

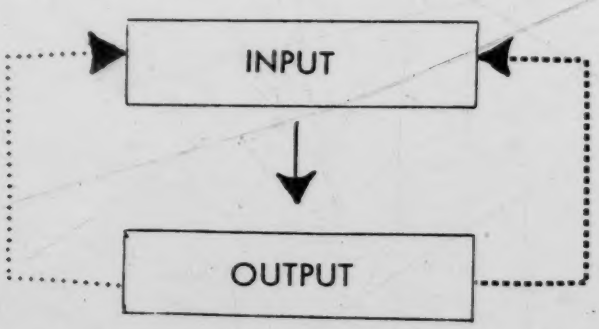


Figure 5.3

An understanding of input and output can be applied to a re-examination of this study's hypothesis as stated in Chapter 1. It states that the rate and scale of output increases in a longshore direction due to an increase in the scale of input. Output in this case is typified by mass movement processes while input refers to tidal range. This amounts to an examination of one closed system within an open system model. This, however, can be defended. The basic aim of this study has been a comparison of longshore processes. Chapters 2 through 4 have examined all significant inputs to the entire system. It is understood that such variables as climate and lithology play an important role in coastal dynamics. However, the only input variable, with the exception of wave energy, which displays a consistent longshore change is tidal range. (Wave energy, as expressed by Kb values (Chapter 3) decreases in an easterly direction). All other input variables must be treated as constants when comparing coastal dynamics on a longshore basis.

b) Changes in input - output:

Several changes in output in an easterly direction have been observed and at least one other may be inferred. Most importantly, the rate and scale of mass movement was shown in section 4.4.2.b to increase in an easterly direction. Cove indentation is seen to increase in the same direction. Platform gradients increase eastward from Parker's Cove to Baxter's Harbour. Although no comparative evidence is presently available, it may be argued that the

range of fluctuations in groundwater head must also increase eastward in direct correspondence with the tidal range.

The decrease in wave energy, in terms of Kb values, in the face of increasing output, infers the relative insignificance of wave refraction as a major process component. It also signifies that some other control or process factor must be responsible for the longshore changes observed. The only logical alternative which can be suggested from this study is tidal range.

Only recently have workers (Trenhaile, 1973, 1974a, 1974b, 1978; Kirk 1975; Trenhaile and Layzell, 1979) found a definite correlation between shore platform gradients and tidal ranges. This correlation may be explained in terms of vertical cliff base range over which wave attack is concentrated. However, such findings must also have definite implications with respect to backshore processes (i.e. mass movement). A steeper platform quite possibly contributes to faster debris removal and a greater exposure of the cliff face to marine attack. A steeper platform may lead to a more rapid rate of tidal rise allowing a stronger perturbation of groundwater head.

Subaerial processes also appear to respond to tidal range increases. This is achieved principally through increases in cleft water pressure arising from groundwater head increases. This suggests the possibility that increasing effectiveness, upbay, of marine processes may be accompanied by a corresponding increase in the

effectiveness of subaerial processes in the same direction. It is impossible, however, to state with certainty that the relative importance of marine or subaerial processes increase or decrease in any particular direction.

c) Feedback links:

In terms of feedback links, an easterly increase in tidal range produces two probable sequences of events. The first is the direct effect of tidal range on groundwater head and the cliff base. The outputs from this can act to produce a second sequence through positive feedback. For example, cliff failure along a particular cliff face may lead to relaxation of compressive stress within the new surface zone and result in tension crack development. The debris fronting the cliff may lead to localized refraction patterns and concentration of energy on exposed cliff sections. Greater cove indentation may lead to increased exposure to subaerial and marine processes.

Positive feedback most certainly plays a strategic role in coastal dynamics within the study area. Negative feedback is important also, as indicated in Figure 5.1. Output may lead to a dampening of further short term action allowing a relaxation period. Thus, at any one time, as stressed in Figure 5.2, positive and negative feedback may be simultaneously important. This tends to confirm King's (1970) observations.

5.4 Potential Application

a) Residential development:

This study shows conclusively that significant

amounts of erosion are taking place along the south coast, Bay of Fundy. Along resistant, cliffed sections, retreat in the order of centimetres may occur on an annual basis. However, on poorly resistant sections retreat is more likely to be measured in metres annually. This does not mean that cliffed sections are constantly retreating several centimetres per year or that till exposures are cutting back at a rate of some metres per year. In examining erosion of this study area, the concept of relaxation time, that is the episodic nature of erosional events must be strictly adhered to, because it best fits reality.

The fact that exposed till sections may retreat several metres in a season presents coastal erosion as a natural hazard of potential significance. From Hampton eastward such poorly resistant shorelines are popular locations for residential and recreational developments. Two sites, Chipman Brook and Olgilvie's Wharf (Figure 5.4) have already seen developments lost to coastal erosion. The potential for several metres of erosion in a single season has very important implications with respect to such settlements as Turner Brook, Meekin Brook, Morden (Figure 5.5), Port Lorne (harbour) and Hampton, among others. Future development in these areas and in areas such as McNeily Brook should take this into consideration.

b) Tidal power development:

This study has also demonstrated that the most probable major factor contributing to local coastal geomorphic evolution is that of tidal range. Clark (1978) has shown

Figure 5.4 a - Bank recession at Morden. The bank has retreated to a position approximately 8 m from the house. Boulders have been placed in the most seriously affected area as a makeshift seawall.

Figure 5.4 b - Demolished cottage at Olgilvie's Wharf. The July, 1978, storm berm lies slightly shoreward of the building foundation remnants.

that construction of barriers for the generation of tidal power in the Minas Basin and/or Chignecto Bay will lead to changes in amplitude of mean tide at Saint John from 1.0 meters (present value - Canadian Hydrographic Service, 1978) up to 7.1 meters. For large tides, the comparable figures are 0.2 meters and 9.2 meters. This would produce an increase in range of up to 9.4 meters. Comparing this to the present longshore increase in range from Parker's Cove to Baxter's Harbour (6.3 meters), which is suggested to be responsible for initiation of present and near-past coastal geomorphic changes, underlines the very real threat that is posed to the present coastline by such development.

5.5 General Conclusions

Although time constraints and data limitations have restricted this study, several conclusions may be made on the basis of the foregoing discussions. These conclusions are based mainly on the available empirical evidence, tempered slightly by intuitive reasoning.

Of great importance is the fact that cliffs in the study area are undergoing consistent erosion. Rates of erosion may vary due to the episodic nature of shoreline retreat. According to Sunamara's (1973) review of coastal cliff erosion rates around the world, no previous attempt has been made to quantify rates of erosion of basalt cliffs. The only remotely related study referred to by Sunamara (1973) was by Sorensen (1968) who, in connection with a much broader study, examined an isolated point at

Rockaway Beach, California. This point is composed of "... ..Franciscan volcanic and metavolcanic rocks that are somewhat more resistant than the conglomerate at Santa Cruz". He calculated a cliff recession rate of six inches (15 centimeters) per year. The cliff retreat rate calculated for the Bay of Fundy basalts (30 centimeters over a 15 year period, an average of 2 centimeters per year) is in the same order of magnitude as Sorensen's (1968) value insofar as the California coast is a higher energy environment.

The role of subaerial processes within the study area is of great significance. Characterized mainly by processes of mass movement, the process factors of cleft water pressure, frost wedging/shattering and related weathering mechanisms are considered to contribute to most, if not all erosional events. Factors of lithology, climate, bathymetry, morphology and vegetation are relatively constant throughout the study area. The only major factor which varies significantly along the coast is tidal range. The eastward increasing tidal range also relates to increasing groundwater heights. An increase in groundwater head in turn leads to increased cleft water pressures, enhancing mass movement potentials.

Mass movement potential may, in some cases, also be affected by factors governing toppling failure, as outlined by De Freitas and Watters (1973) and discussed briefly in Chapter 3. In such circumstances the factors of uniform lithology and, in particular, low seaward dips of flow

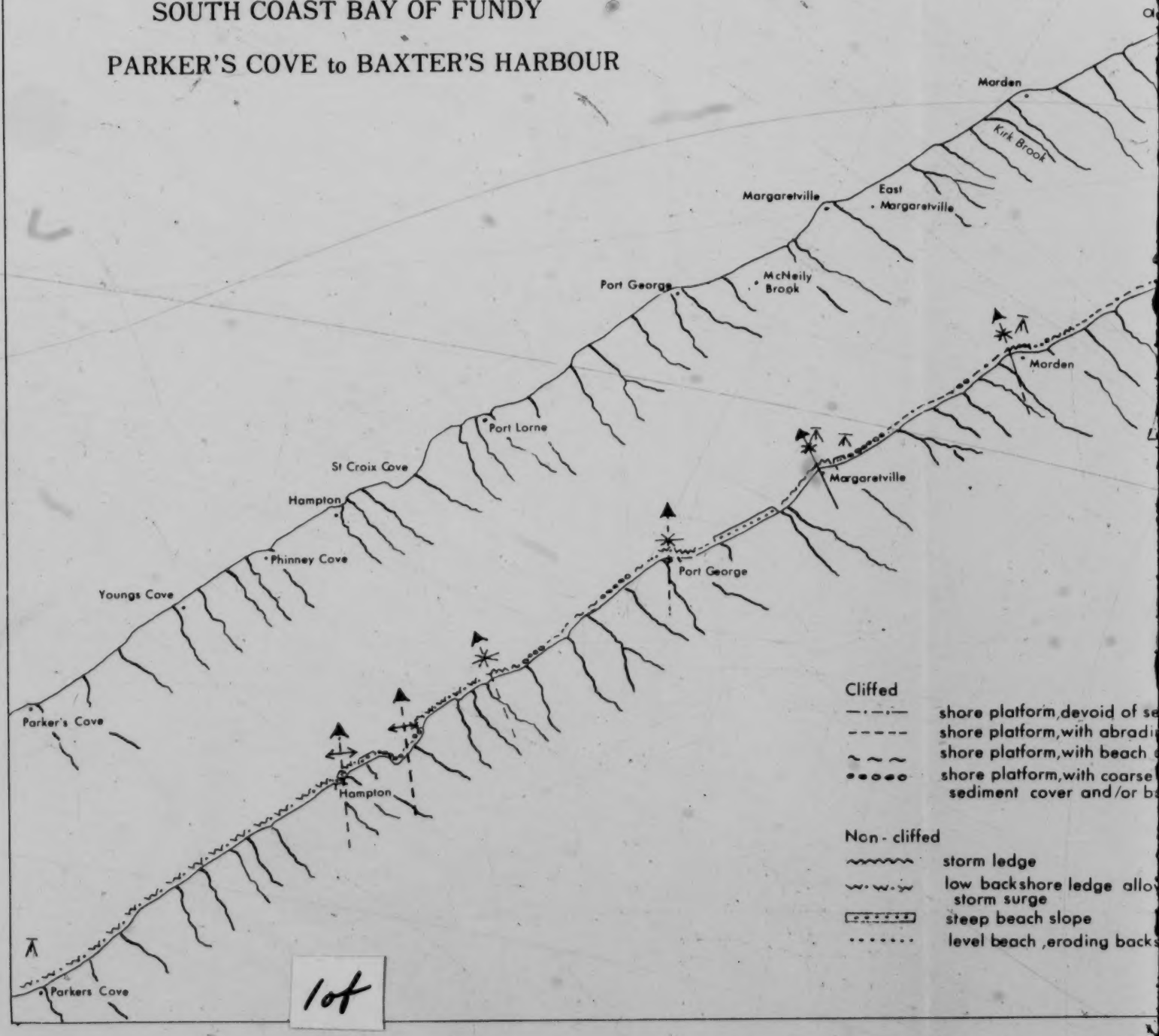
contacts (between 3-5°, Hudgins, 1960), combined with marine erosion may also create a situation favourable to mass movement processes.

Marine processes may, however, be of lesser importance than subaerial processes with respect to rates of cliff erosion. Perhaps the most significant long-term effects of marine processes are debris comminution and longshore sediment transport. Debris removal leads to further cliff base exposure promoting instability through both marine processes and subaerial processes. Of marine processes the most important factor must be that of increasing tidal range, a factor that appears to strongly enhance the subaerial component. Tidal range also controls platform slope and is directly related to the cliff base range over which direct marine forces are concentrated. The rate and scale of mass movement along the south coast, Bay of Fundy, are directly related to an increasing tidal range in an easterly direction. Tidal range influences both subaerial and marine processes which control coastal dynamics.

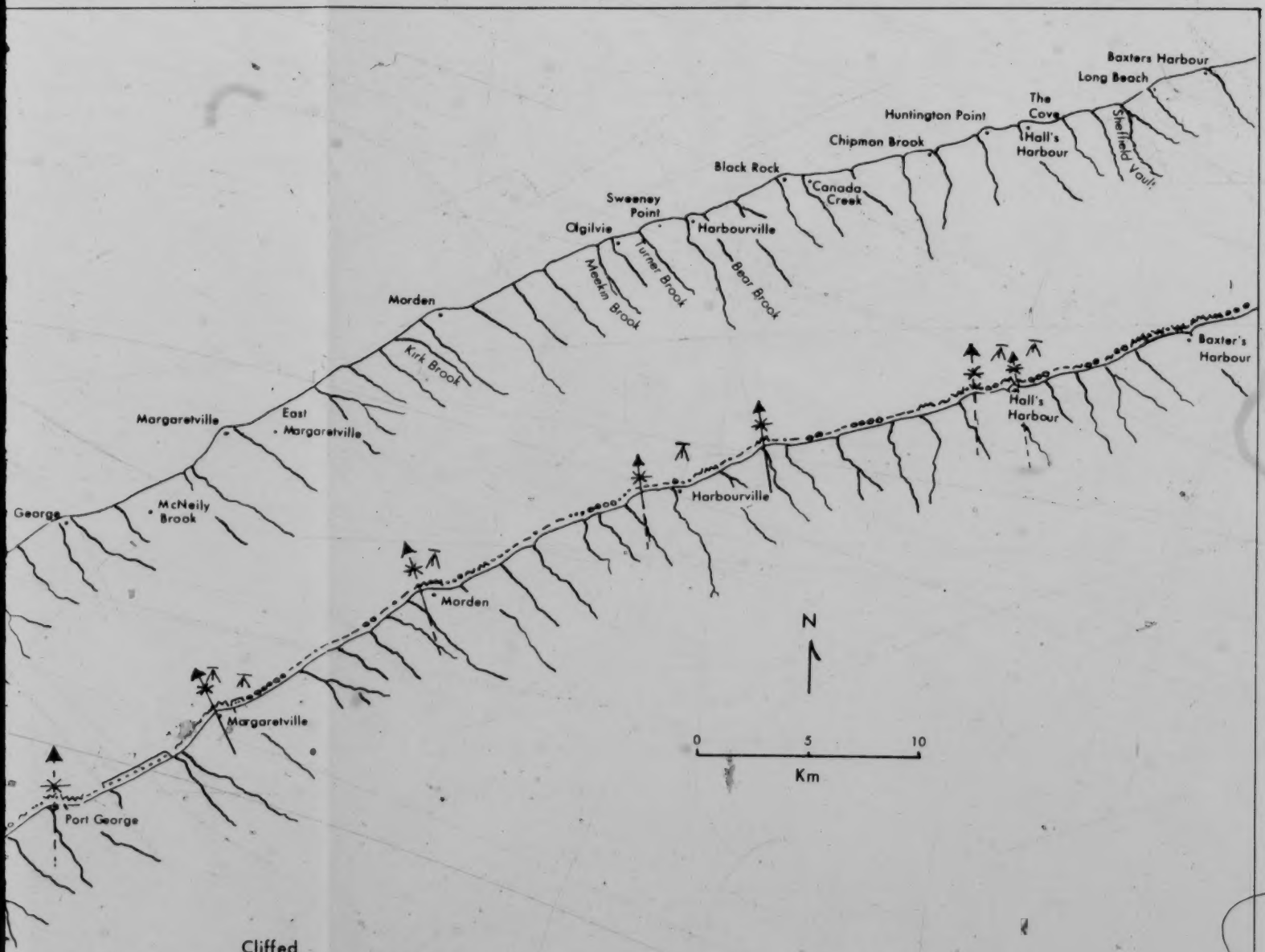
Figure 5.5 - Map of study area showing:
a) Locations of areas mentioned in text, and
b) i) Location of survey sites, ii) Coastal classification and iii) Structural geology.

SOUTH COAST BAY OF FUNDY

PARKER'S COVE to BAXTER'S HARBOUR



1 of



Cliffed

- shore platform, devoid of sediment
- shore platform, with abrading tools
- shore platform, with beach at high tide
- shore platform, with coarse protective sediment cover and/or boulders

Non-cliffed

- storm ledge
- low backshore ledge allowing storm surge
- steep beach slope
- level beach, eroding backshore

- survey sites
- synclinal trough line (defined)
- synclinal trough line (approximate)
- anticlinal crest line (approximate)

Structural geology compiled by A.E. Hudgins, 1960

Coastal classification mapped by K.W. Thomson, 1978, with reference to 1975 aerial photography

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APPENDIX I

WAVE DATA

Wave Data

Data Source: Canadian Hydrographic Service Waverider Buoys Report #s 27-3, 29-3, 56-3, 40-5, 43-2.

Waverider Buoy	Period of Observation	Peak Period with Corresponding Wave Height (sec)	(m)	Peak Period and Frequency of Occurrence (sec)	(%)
Minas Basin (27)	30/6/75 to 1/12/75	4	1.5	3	45
Tiner Point (40)	26/1/77 to 6/3/78	9	4	9	28
Saulnierville (143)	27/5/77 to 8/5/78	10	4	6	16
Colson Cove (56)	21/4/77 to 7/3/78	9	2.8	6	18
Point Lepreau (29)	21/6/75 to 1/6/76	9	5	4	18

APPENDIX II

CLIFF HEIGHT AS DETERMINED BY PARALLAX MEASUREMENTS OF AERIAL PHOTOGRAPHY

Cliff Height as Determined by Parallax Measurements of Aerial Photography

Note: Although these measurements are seen to differ from actual measurements made in the field, this difference is consistent between areas, with the values below, in most cases, greater than the actual values. However, this information does serve as an adequate means of comparing relative cliff heights between coves.

Margaretville:

Source = 1973 photography A73012, 221-222 scale 1:17500

Distance east of Margaretville wharf (Km)	Cliff height (m)
0.35	8.8
0.50	13.8
0.70	16.3
0.95	18.5
1.25	22.5
1.50	33.8
1.65	32.2
1.80	34.7

Morden:

Source = 1973 photography A73012, 100-102 scale 1:17500

Distance west of former wharf (Km)	Cliff height (m)
0.45	4.2
0.55	18.9
1.00	21.7

Distance east from former wharf (Km)	
0.35	36.4
0.50	22.6
0.65	23.1
1.00	40.6
1.15	41.7
1.50	42.3
1.70	31.0

Harbourville:

Source = 1973 photography A73012, 44-45 scale 1:17500

Distance east of Harbourville wharf (Km)	Cliff height (m)
0.35	16.6
0.55	34.1
0.85	34.4
1.05	32.4
1.20	37.5
1.40	37.2
1.55	35.3

Hall's Harbour - The Cove:

Source = 1973 photography A73012, 27-29 scale 1:17500

Distance east of Cranberry Point (Km)	Cliff height (m)
0.18	11.5
0.30	20.7
0.45	44.6
0.70	54.7
1.25	51.0
1.50	40.3
1.65	40.3

APPENDIX III

OUTLINE OF STATISTICAL METHODS EMPLOYED IN DATA ANALYSES

Outline of Statistical Methods Employed in Data Analyses

A. Least Squares Regression:

Purpose - as a measure of gradient for surveyed transects.

Method - obtained through a MIDAS program which provided values from the survey data for the regression equation.

$$y = a+bx$$

where a is the y intercept and b is the regression coefficient or slope of the line. Results are presented in Table 4.2.

B. Polynomial Regression:

Purpose - to obtain the best "line of fit" to describe the relationship between shore platform gradients and longshore distance.

Method - obtained through a MIDAS program which provided values for the quadratic equation

$$y = a+a^2+bx$$

from an analyses of the slopes and position of twelve sites. Results are presented in Figure 4.5.

C. Student t Test:

Purpose - to test for independence between groups, specifically; i) between platform gradients of Parker's Cove, Margaretville, Morden and those of Hall's Harbour.
ii) between gradients adjacent to east and west sides of wharves or storm ledges.

Method - by means of a MIDAS program. The results may be summarised as follows:

Comparison	Significance Level
Downcoast (Parker's Cove, Margaretville and Morden) VS. Upcoast	.0002
West side wharves VS. east side of wharves	.0017

Outline of Statistical Methods Employed in Data Analyses

(continued)

D. Standard Deviation:

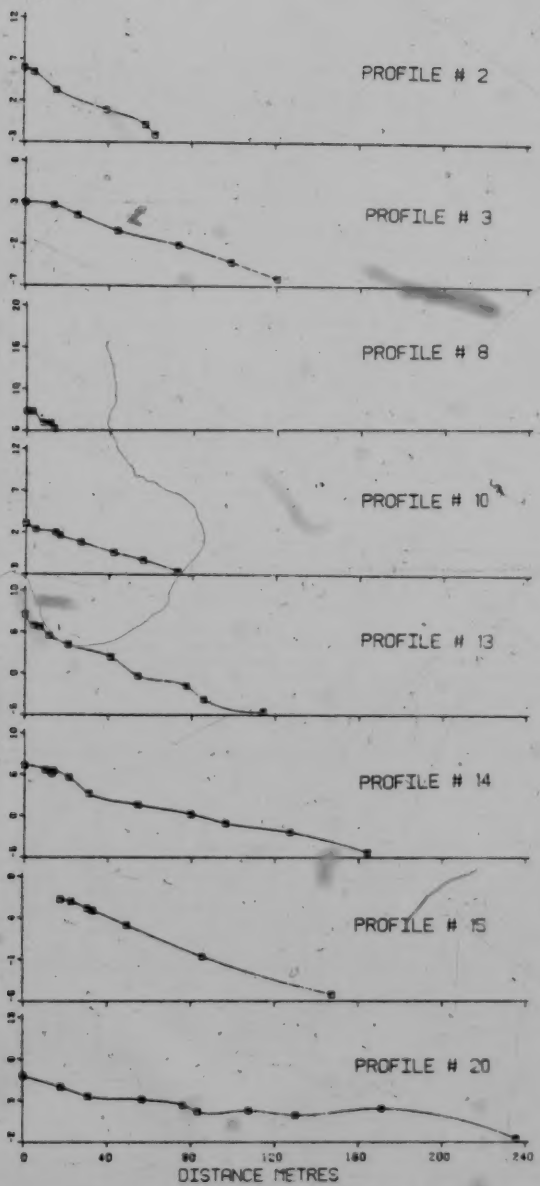
Purpose - to determine dispersion within climatic data, specifically, atmospheric precipitation totals (Table 2-2) and freeze thaw cycles (Tables 2-1).

Method - Application of data to equation

$$s = \frac{(x-\bar{x})^2}{n}$$

APPENDIX IV

SURVEYED PROFILES OF SITES WITHIN THE STUDY AREA WHICH HAVE NOT BEEN PRESENTED IN THE TEXT



Surveyed profiles of study area, not included in text.